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MINERALOGY AND GENESIS OF SOILS OF THE UPPER SUBALPINE BIOCLIMATIC SUBZONE, SUNWAPTA PASS, ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Mineralogy and Genesis of Soils of the Upper Subalpine Bioclimatic Subzone, Sunwapta Pass, Alberta, submitted by C.A. Scott Smith in partial fulfilment of the requirements for the degree of Master of Science.

DEDICATION

In memory of Richard Fernand Levésque (1951-1974) and the friendship and inspiration he gave to us all.

ABSTRACT

Unusual luvisolic-like morphologies were observed in some profiles in high elevation ($>$2,000 m) soils of the upper subalpine bioclimatic subzone in Sunwapta Pass, Alberta. The soils had a distinct textural discontinuity, the lower material being a dense, highly calcareous (50 - 80% $CaCO_3$ equivalent) glacial till overlain by a friable silty material of low coarse fragment content and variable thickness. After detailed field reconnaisance eight pedons were sampled, of which four soils, two exhibiting anamalous luvisolic-like morphologies, and two exhibiting the more conventional Podzolic morphology, were selected for detailed study and used to test several hypothesis of parent material origin and pedogenesis.

Both petrographic analysis of the fine sand fraction, and particle size distribution, indicated the silty surficial parent material to be eolian in origin, and comprised of both local detritus and volcanic ash. No discrete straigraphic layers of either the loess or ash were preserved, and the material appeared to be mineralogically uniform. The mineralogy of the glacial till reflected that of local geologic materials and was dominated by carbonate minerals. Apparent textural B horizons were concluded to have developed from a combination of processes. Relative clay increases, and the strong subangular blocky structure of weathered till horizons where shown to have developed primarily as a result of the selective dissolution and removal of carbonates from the soil matrix. There was evidence to suggest that much of the illuvial clay seen in thin section may have been inherited through processes no longer operative. It was concluded that lessivage was an inconsequential

contemporary processes in these soils. The fabric of till horizons tended to be granoidic or granoidic-porphyric, with most pedologic features resulting from carbonate removal. The clay minerals within the till horizons were largely unweathered and consisted of muscovite, chlorite and minor amounts of kaolinite. Within the upper material the clay fraction was dominated by amorphous material. Mica had been altered to vermiculite, which in turn had been partially interlayered with hydroxy material produced through the weathering of the volcanic ash component. There was no evidence of smectite or regularly interstratified minerals in these soils. Free Fe present within the soils was demonstrated to originate from both ash and non ash sources, and reached a maximum within horizons formed through the weathering of till. The soils were generally classified as Orthic Humo-Ferric Podzols.

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Chapter 1

INTRODUCTION

During the summer of 1976, soil survey in conjunction with the Banff-Jasper Biophysical Inventory, identified bisequa soils exhibiting luvisolic-like properties within the upper subalpine bioclimatic subzone at Sunwapta Pass. Rather than Luvisolic soils, it is thought that the environment associated with the higher elevations in the Cordilleran region, is more conducive to the formation of soils of the Podzolic and Brunisolic orders (Canada Soil Survey Committee 1978a).

Based on these observations, it was felt that a study to evaluate both the complexities of the parent material, and the seemingly anamalous luvisolic-like solum development was justified.

Previous Soil Related Studies

It was not until 1949 that the Banff-Jasper highway was completed and vehicle access gained into the Columbia Icefields area. A reconnaisance study of the glacial geology of Sunwapta Pass soon followed (Jennings 1951) and attempts were first made to interpret the post glacial history of the area (Heusser 1956). Some years later, selected profiles were analysed and prepared as part of a soils tour through the central Alberta Rockies (Alberta Soil Survey 1963). Examination of surficial geology of the Banff area (Rutter 1965) provided a characterization of Wisconsin ice movements in the vicinity of the continental divide, and an idea of mineralogy of the glacial tills within the Bow Valley. Volcanic ash

deposits within the region became a popular research subject in the late sixties and resulted in a series of articles which demonstrated the areal distribution of this material, and provided basic elemental and petrographic characteristics of these deposits (Westgate and Dreimanis 1967, Smith and Westgate 1969, Westgate et al 1970). The first study relating specficially to volcanic ash layers within the soil profile followed (Beke and Pawluk 1971). At this time Pettapiece (1970) had completed a pedological study in the North Saskatchewan River valley in the Front Ranges. His work in that location remains geographically the closest soil research to this study and has provided an excellent reference for correlation and comparison of mineralogical suites and clay mineral weathering (Pettapiece and Pawluk 1972).

Recently a wide variety of research has taken place to attempt to uncover past environmental conditions. Numerous paleosols have been described and interpreted (Dormaar and Lutwick 1975, Reeves and Dormaar 1972, King et al 1978). As well, all major river valleys leading out of the Rocky Mountains in the Banff-Jasper region have been described in terms of their glacial geomorphology. The Bow River (Rutter 1972), Red Deer River (Harris and Boydell 1972), North Saskatchewan (MacPherson 1970), and the Athabasca River (Roed 1968) have all received attention. Several soil studies have taken place within the subalpine environment in Banff National Park where attempts were made to reconstruct the soil site histories in terms of the classic soil forming factors (Brewster 1974, Mark 1974). The soils and vegetation of the Sunshine Basin alpine area were examined and the dominant pedological processes (Knapik 1973) and soil vegetation relationships (Knapik et al 1973) were described.

The first full scale micromorphological study was carried out on three alpine soils by Pawluk and Brewer (1975b) and this research proved invaluable to this study in correlating soil fabrics and pedological features as viewed in thin section.

At present there are biophysical surveys being conducted in both Banff and Jasper National Parks (Holland 1976). These, along with completed soil surveys of Waterton (Coen and Holland 1976) and Yoho (Coen et al 1977) National Parks provided data on the soil subgroups of this mountainous region, their distribution, and their ecological relationships within the various bioclimatic zones.

This study deals with soil development within the upper subalpine bioclimatic subzone at Sunwapta Pass (Wells et al 1977). Numerous studies have been undertaken in very similar environments in other geographical locations. In particular, the work of van Ryswyk (1969) in south central British Columbia, Bockheim (1972) at Mount Baker, Washington, and Sneddon et al (1973) in the interior of British Columbia have helped to solve problems encountered in this study. Their previous grapplings with methodology and interpretation made this job easier, and brought to light the striking similarities in soil environments in the upper subalpine, in spite of wide geologic and geographic separations.

The Study Area

The Sunwapta Pass area represents a major hydrologic divide in the Rocky Mountains. Meltwaters from the Athabasca glacier feed into the Sunwapta River and ultimately into the Mackenzie watershed and on to the Arctic Ocean. Waters from drainages south of the divide run into the North Saskatchewan River and eventually into Hudson Bay and the Atlantic Ocean. The divide is also the boundary between Banff

National Park to the south and Jasper National Park to the north. The study area spans this boundary, and hence sites are located in both parks. Sunwapta Pass is located at approximately 52° 12' N and 117° 11' W (Figure 1). Jennings (1951) provided a review of the geographic location and general topography of the area.

Bedrock and surficial geology. There are, as yet, no geologic survey data available for the study area and so only a brief discussion is possible regarding the regional geology. Orogeny is known to have occurred during the Tertiary period (Jennings 1951). All rocks west of the Simpson Pass thrust fault (i.e. west of the Icefields Parkway) consist of relatively pure limestones and dolomites of the Middle Cambrian except for calcareous shales and argilaceous limestones of the Stephen Formation. East of this fault are younger Paleozoic carbonate rocks with some sandstones at the top of the Ordivican and some shales in the Devonian and Mississippian (E.W. Mountjoy, McGill University, personal communication).

The major landforms of the area are attributable to the Wisconsin glaciation. Throughout this period Mount Athabasca acted as an ice accumulation center. Cirques indicate ice moved north, east and south from Mount Athabsca. Also, in the ice filled main valley, the divide separating the north-flowing ice from the south-flowing ice appeared to have shifted periodically from what is now Sunwapta Pass to the present location of the toe of the Dome and Athabasca glaciers (Jennings 1951). It was concluded that the maximum ice thickness was about 2,000 feet in the pass (i.e. reached a maximum of 8,800 - 9,000 feet asl). Both Rutter (1972) and MacPherson (1970) presented evidence for multiple glaciation. This seems not to have been the case at Sunwapta.

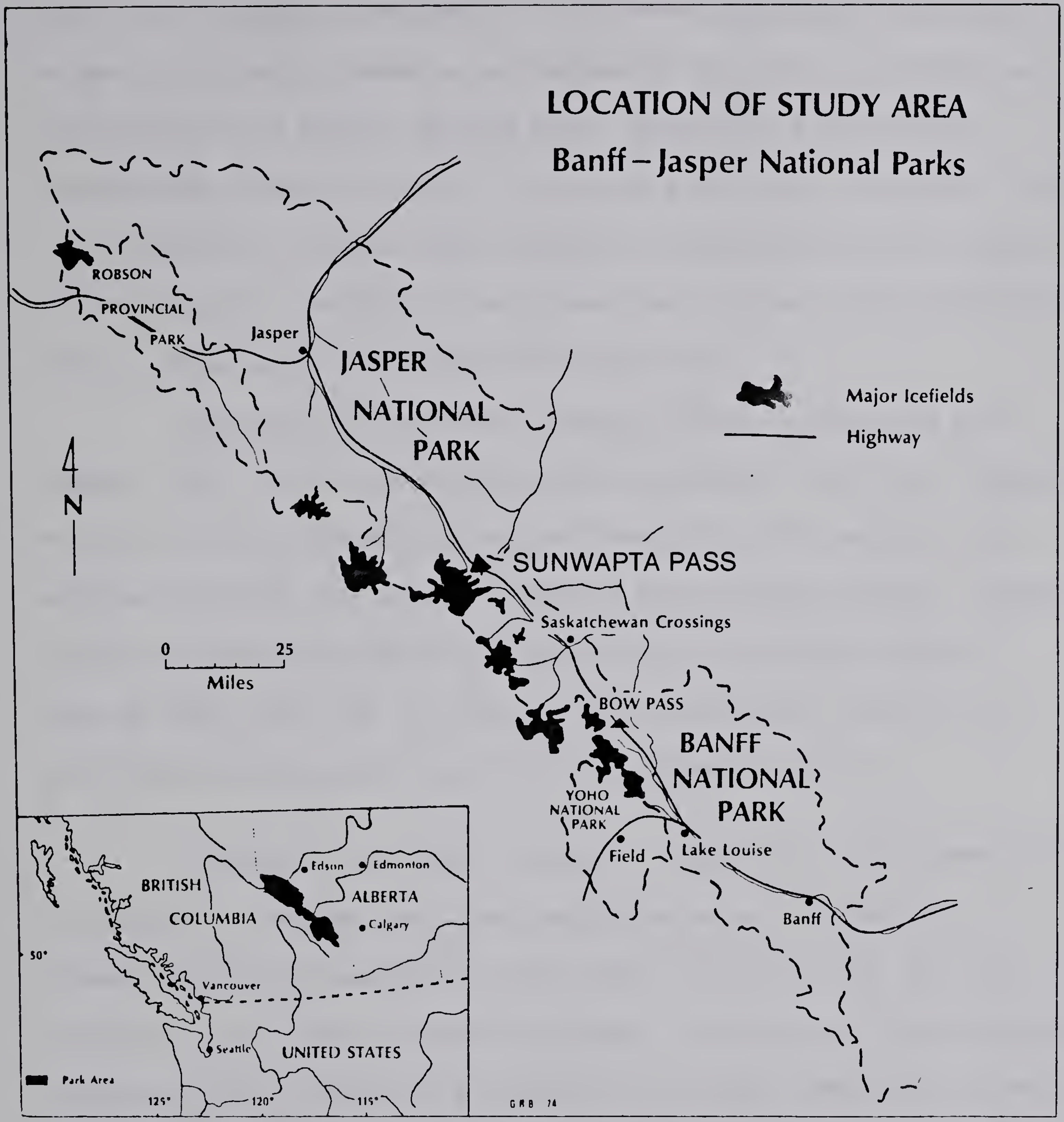

Figure 1

Location of the Sunwapta Pass study area in Banff-Jasper National Parks, Alberta (adapted from Brewster, 1974)

Either the glaciers at the end of the Wisconsin glaciation eradicated evidence of previous deposits or, because of the higher elevation, no real interglacial periods existed here. MacPherson felt that the Saskatchewan Crossing area was ice-free by 9,330 YBP. The nature of the till deposits at Sunwapta lead Jennings to believe that final deglaciation was rapid. Therefore it would seem that the pass area would have been ice-free between 8,000 and 9,000 years ago.

Numerous smaller glacial features exist in the study area. Heusser (1956) has described the moraines associated with the neoglacial advances of the Athabasca glacier and Jennings (1951) described the moraines deposited during this period by small cirque glaciers. Paleopedological evidence (Reeves and Dormaar 1972) and pollen records (Heusser 1956) date the altithermal period as occuring from 8,000 to 5,000 YBP although exact dates vary from author to author.

Climate. The present climate of the study area is summarized in Table 1. A weather recording station has been in operation at Columbia Icefields sporadically since 1962, but only since 1972 has continuous, year long data been collected. As there are not enough data to develop long term averages (minimum of 10 years) comparison is made with Jasper for the year 1976 (Tables 2 and 3). The temperature regime at Sunwapta was considered less continental than at lower elevations such as Banff and Jasper townsites (Janz and Storr 1977). The average annual range between the extreme high and low temperature was estimated to be 75^{0}C. This was less than that of other stations east of the continental divide and was presumed to be a function of Pacific air moving unobstructed over the Columbia Icefields into the main valley at Sunwapta. The average number of days per year with precipitation is

Table 1

Temperature and precipitation data for Columbia Icefields (1962-1978)*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Mean daily maximum	-11.7	-3.9	-1.6	4.6	9.6	12.2	15.0	15.0	9.8	3.4	-4.5	-7.7	
°C	(4)**	(5)	(5)	(5)	(5)	(8)	(10)	(12)	(9)	(6)	(6)	(5)	
Mean daily minimum	-18.4	-13.9	-13.2	-9.6	-2.6	0.4	2.9	3.4	-0.7	-6.8	-12.3	-16.2	
°C	(4)	(5)	(4)	(4)	(5)	(8)	(10)	(12)	(9)	(6)	(6)	(5)	
Mean daily temp.	-13.8	-8.8	-7.0	-2.3	3.3	6.3	9.0	9.2	4.4	-1.4	-8.7	-12.5	
°C	(5)	(6)	(5)	(5)	(5)	(8)	(10)	(13)	(10)	(7)	(7)	(6)	
Total precipitation	140.5	73.9	104.9	64.3	37.6	67.6	63.3	48.7	60.9	81.5	90.2	101.34	935.2
(mms)	(5)	(6)	(5)	(5)	(5)	(7)	(10)	(13)	(10)	(7)	(7)	(5)	

* Source - Atmospheric Environment Services; Monthly Record of Meteorological Observations in Canada.

** Represents the number of observations (years) on which the mean value is based.

Table 2

Comparison of temperature and precipitation (1976),
Columbia Icefields vs. Jasper Townsite*

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
JASPER TOWNSITE	Temp. (°C)	-7.2	-5.6	-3.3	4.4	8.9	10.5	13.9	13.9	11.7	4.4	-1.7	-4.4	3.9
	Precip. (mm)	27.4	12.7	11.7	12.9	18.5	30.2	45.2	90.4	41.9	28.9	14.2	28.2	362.2
COLUMBIA ICEFIELDS	Temp. (°C)	-11.7	-11.1	-10.5	-7.7	2.8	4.4	8.8	7.2	-1.1	-6.1	-7.8	-7.8	-1.6
	Precip. (mm)	86.6	140.5	80.5	45.2	31.0	35.0	50.3	74.2	53.1	40.9	47.9	82.6	767.2

* Source - Alberta Environment, Climate of Alberta - Report for 1976.

Table 3

Comparison of monthly temperature extremes (1976)
Columbia Icefields vs. Jasper townsite (°C)*

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
COLUMBIA ICEFIELDS	maximum	4.4	2.2	2.2	11.1	13.3	21.6	26.1	24.4	18.9	15.5	6.6	3.9
	minimum	-31.7	-28.3	-35.0	-20.0	-8.3	-6.7	-3.3	0.5	-7.2	-14.4	-18.9	-21.7
JASPER TOWNSITE	maximum	9.4	8.3	10.5	20.5	22.2	26.1	28.3	26.7	25.5	19.4	12.2	6.6
	minimum	-28.9	-22.8	-32.8	-13.8	-2.7	-2.7	2.2	2.7	-5.5	-8.3	-15.5	-12.8

* Source - Alberta Environment, Climate of Alberta - Report for 1976.

about 170. The limited data that existed indicated precipitation to occur one day out of two in the summer, and two days out of three during the winter months. There was roughly double the precipitation at the Columbia Icefields station (Table 2) than at Jasper townsite. An estimated 80% of the precipitation at Sunwapta falls as snow. It remains permanently on the ground from early November until mid June. There are no months without frost. While the temperatures do not vary as much as one might expect between the stations, cooler temperatures and increased precipitation would result in great differences in evaporization rates (Janz and Storr 1977). This would create a cold to very cold, humid, soil regime for the area.

Vegetation. The study area was located within the upper subalpine bioclimatic subzone as defined by Wells, Corns and Allan (1977). The forest vegetation was dominantly an Engelmann spruce, subalpine fir woodland, more precisely belonging to the *Picea engelmanni/Abies lasicarpa - Phyllodoce glanduliflora/Cassiope mertensiona* type. Where the aspect was more southerly, or sample sites located at lower elevations, the forest canopy became more closed. Here the vegetation was classified as belonging to the *Picea engelmanni/Abies lasiocarpa - Vaccinium scoparium* type. The reader is referred to Appendix 1 for a complete description of forest stand structure and species composition at each site.

The Problem

Parent materials have a profound effect on soil development and were used by the Banff-Jasper biophysical crew (Holland 1976) as an initial criteria to divide soils into map units. This split was

based on whether the parent material, derived primarily from local geologic strata, was calcareous or not. In the study area the glacial till parent material was calcareous but varied to some degree in effervescence, texture, and colour from one site to the next. Added to this was an almost ubiquitous surface veneer found throughout the Rocky Mountains (Coen and Holland 1976, King and Brewster 1976, Coen et al 1977). This surface silt loam veneer varied from 14 to 27 cm in thickness in the study area and showed variable profile development. Initial field observations indicated that the Ae horizons formed in this material were, without exception, coarse fragment free. An underlying strong reddish B horizon was generally, but not always, without particles greater than 2 mm in diameter.

Volcanic ash layers have been identified and dated nearby at Saskatchewan Crossing (Westgate and Dreimanis 1967, Westgate et al 1970). Geomorphologists (MacPherson 1970, Rutter 1965) have described eolian activity concurrent with deglaciation in terms of supraglacial and proglacial origins, and then again during the altithermal period about 6,000 years ago, (Huesser 1956), when conditions were conducive to wind transport of unconsolidated materials. Pettapiece (197) alluded to this apparent two cycle system of deposition of local detritus. Eolian activity continues in the mountains today and has been studied in detail in the Athabasca River Valley (Dumanski and Pawluk 1971).

As outlined earlier, pedologists involved with the Banff-Jasper Biophysical Inventory, described soils which exhibited luvisolic-like properties within the upper subalpine bioclimatic subzone at Sunwapta Pass. A unique B horizon with well developed subangular blocky structure appeared, based on field morphology, to contain all the

characteristics of a true argillic horizon. Similar soils, associated with calcareous till, have been encountered sporadically elsewhere in the Rockies at elevations above 2000 m, both within the Banff-Jasper region (R.E. Wells, B.D. Walker, Alberta Institute of Pedology, personal communication), and in southwestern British Columbia (L.E.H. Lacelle, Resource Analysis Branch, Kelowna, British Columbia, personal communication). These observations are in conflict with the generally accepted concept of Gray Luvisols occurring only at lower elevations in the montane and lower subalpine zones (Pettapiece 1970, Coen et al 1977, Valentine et al 1978). The upper subalpine is characterized by a harsher climate than that found at lower elevations. The lower temperatures, higher precipitation and more acidic litter of the upper subalpine vegetation are thought to result in the formation of soils of the Podzolic and Brunisolic orders (Canada Soil Survey Committee 1978a).

An upper B horizon, showing variable development in terms of colour and thickness, was also present within the solum of these soils. Lithic fragments, often calcareous, which had been incorporated into the base of the upper parent material appeared to be undergoing severe weathering. Morphologically this weathering took the form of a dark, organic rich "rind" or "ghost" which contributed to the variable colour development and perhaps iron content of these horizons.

These observations, result in the implementation of a study to evaluate both the material present within the study area and the observed luvisolic-like solum development. The objectives of the study are summarized as follows:

1. (a) To characterize the glacial till parent material in terms of chemical and physical properties, and to evaluate the mineralogical uniformity of the deposit.

   (b) To determine the origin and mineralogical nature of the surficial silt loam parent material.

2. Elucidate the processes responsible for the formation of an apparent textural B horizon within an ecological zone generally considered outside the environmental range of the Gray Luvisolic great group.

3. To determine whether or not the bright red horizons of the upper solum represent Podzolic B horizons and to determine the origin and distribution of free Fe and Al in these soils.

The study dealt first with the evaluation of parent materials, and then examined the pedogenic processes operative within these materials. The thesis is arranged in chapters, each dealing with one of the three major objectives outlined above.

Experimental Design

The study was confined to an east-northeast aspect on a forested inclined morainal landform. Sampling sites were distributed along this slope from the Athabasca glacier south to Parker's Ridge. Sites were chosen, after intensive field observations, to represent typical soil morphologies of the area. The pedons sampled were located on stable, well drained sites of similar parent material, aspect, slope and vegetation type (Figure 2). One exception was pedon B1 which was located on a fluvially eroded site and was used for comparative purposes. Sites were choosen so as to keep as many of the soil forming factors constant as possible, and in this way limit the influences which might have resulted in the observed range of soil morphologies. It became

Figure 2

A stereopair showing the Sunwapta Pass study area and sampling sites along the forested slope - Scale of photograph approximately 1:60,000.

obvious in light of analytical findings that this objective was, in fact, only partially achieved.

Sampling of eight pedons was conducted in August and September of 1977. Pits, approximately 0.75 m by 1.0 m were dug to a depth of at least 1 m. Bulk samples of major horizons, and undisturbed monoliths were obtained. Soil profile and site descriptions were prepared. Forest stand structure was described and species lists compiled for each site.

Routine analyses were conducted on 46 samples. When these were completed, four of the sites were selected for detailed mineralogical and morphological study. These included two sites exhibiting luvisolic-like characteristics and two exhibiting the more conventional podzolic-like morphologies.

Data obtained from all eight pedons sampled is contained in Appendix 1. Complete micromorphological descriptions are presented in Appendix 2. The bulk of the discussion in the thesis deals with the four sites selected for detailed study. Pertinent information has been extracted from the appendices and used in the body of the text.

Chapter 2

EVALUATION OF MINERALOGICAL AND MORPHOLOGICAL CHARACTERISTICS OF PARENT GEOLOGIC MATERIALS

Introduction

Soil survey work in the Cordilleran region revealed the wide spread occurrence of a surficial silt loam veneer (Coen et al 1977). It was also known that this veneer may consist of varying amounts of volcanic ash mixed with local detritus. So-called pure deposits of ash have been observed both within the soil profile (Beke and Pawluk 1971, Reeves and Dormaar 1972), and buried more deeply within unconsolidated geologic materials (Pettapiece and Pawluk 1972, Westgate and Dreimanis 1967, King et al 1978). It was known that at least three different ash falls have occurred in the vicinity of Saskatchewan Crossing (Westgate et al 1970). The oldest of these, the Mazama ash, fell during the latter end of the altithermal period, a time when local eolian activity was thought to have been active (MacPherson 1970). This was followed by deposition of the St. Helen's Y and Bridge River ashes (Nasmith et al 1967, Westgate and Dreimanis 1967). The respective thickness of each deposit varies with geographic location. However, values derived from the Saskatchewan Crossing fluvial section indicated that the entire surficial veneer at Sunwapta could not have resulted from ash deposition alone. As outlined, there was evidence to indicate that considerable eolian activity took place both prior to, and concurrent with, major ash fallouts.

Field observations revealed the lower portion of the silty surficial parent material to contain numerous coarse fragments, while the upper portions appeared coarse fragment free. It would seem that some mixing of the glacial till from beneath, with the surficial parent material had taken place. Even though some mixing was evident there was still clear evidence of two morphologically distinct parent materials within the profile of these soils. The initial objective was to describe the origin and mineralogical nature of each of these two parent materials. The following multiple working hypothesis was employed to better organize this portion of the study.

The soils investigated at Sunwapta Pass had formed within a bimodal system of parent materials whereby a glacial till was capped with:

1. A well sorted ablation deposit, reworked by water during deposition or at sometime shortly thereafter, and exhibiting similar mineralogy to the underlying till.

2. A locally derived eolian material composed of detritrus mineralogically similiar to the underlying till.

3. A mixture of volcanic ash and local detritus which was mineralogically distinct from the underlying glacial till.

This chapter first examines the mineralogical and morphological characteristics of the glacial till parent material. Using this information, the properties of the silty surficial parent material are then evaluated in terms of the multiple working hypothesis. In this way, the nature and origin of each was established within the study area. This was considered an essential first step, necessary before features attributable to pedogenesis could be clearly identified.

Materials and Methods

Bulk samples of 2 - 5 kg of soil from all major horizons in the profile were collected from eight pedons within the study area. These were air dried at room temperature and ground by hand with mortar and pestel to pass a 2 mm sieve. Lithic fragments larger than 2 mm in diameter were weighted and expressed as estimated coarse fragment content based on total field sample weight. Subsequent analysis were carried out on materials less than 2 mm only and are heretofore referred to as fine earth samples.

Particle size analysis was conducted using the pipette method following the procedures outlined by Canada Soil Survey Committee (1978b). Samples were pretreated with H_2O_2, dispersed without $CaCO_3$ removal, using Na-hexametaphospate, and mechanically mixed using a milkshake mixer for 5 minutes prior to sedimentation. Sands were dry sieved using a sonic sifter.

$CaCO_3$ equivalent was determined following the procedure of Bascomb (1961).

Measurement of soil pH was conducted on samples suspended in 0.05 M $CaCl_2$ solution using a Corning model 12 research pH meter with glass and calomel electrodes.

Sand mineralogy was evaluated using approximately 10 gms. of fine sand (0.05 - 0.25 mm), separated from the fine earth fraction by wet sieving. This subsample was then separated into four specific gravity fractions, ($<$2.50, 2.50 - 2.72, 2.72 - 2.92, $>$2.92) using appropriate mixtures of the heavy liquids s-tetrabromethane (sp. grav. = 2.96) and bromobenzene (sp. grav. = 1.50) (Jackson 1956). Each separate was then impregnated in a small weighing dish with 3M Scotchcast

Electrical Resin No. 3* (n = 1.57). Thin sections were prepared by mounting the hardened chips with Hysol epoxy resin** onto standard (27 x 46 mm) petrographic slides and ground to a thickness of 30 μm . Selected samples of heavy mineral grains (i.e. those with specific gravity $>$ 2.92) were also mounted in aroclor*** (n = 1.69). One hundred counts were made per slide and results were listed semi quantitatively. This was done both for statistical reasons and due to errors inherent in mineral grain identification. Staining techniques were not employed to differentiate feldspar minerals, hence quartz counts may be overestimated. Many grains were unidentifable due to weathering, oxide coatings, or glass encrustations, and so were grouped into morphological categories.

Thin sections for micromorphological study were prepared as outlined by Brewer and Pawluk (1975a). Where it was not possible to extract monolith samples due to exceedingly gravelly conditions, oriented clods were obtained. All slides were cut to give vertical orientation.

The clay mineralogy was characterized using x-ray diffraction techniques and chemical analysis following the methods outlined in Chapter 3.

Bulk density was determined on clods extracted from major horizons using the paraffin coating method as outlined in Canada Soil Survey Committee (1978b).

Total C was determined by dry combustion using a Leco induction furnace. Total N was determined using a semi-micro Kjeldahl method. Both analysis were conducted following the respective procedures as

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*Available from 3M Company, St. Paul, Minnesota.
**Available from Hysol Corporation (Canada) Ltd., Don Mills, Ont.
***Available through Wards Natural Science Establishment, Inc., Rochester, N.Y.

outlined in Canadian Soil Survey Committee (1978b).

Results and Discussion

Characteristics of the glacial till parent material. A summary of results obtained from routine analysis of IICk horizons composed of glacial till is presented in Table 4. Note the depth at which the IICk horizon begins. This represents the depth to free lime in the profile as indicated by effervescence with HCl. Horizons above this had been largely leached of calcareous material. While the depth to the IICk horizons was somewhat variable, in no cases was it more than 50 cms. The solum development was very shallow, a typical feature of these high elevation soils on calcareous parent material. Increases in the $CaCO_3$ equivalent and pH with depth indicated that weathering was active within the upper portion of this IICk material. The dissolution and subsequent removal of up to 80% carbonate material from these horizons represented a major pedogenic transformation and provided some explanation for the shallow solum development observed here.

The coarse fragment content and texture of the IICk material vary to some degree both within and between pedons. Jennings' (1951) observation of stagnant ice features in the Pass area suggested that considerable amounts of meltwater were involved in the deposition of much of this material. Dreimanis (1975) described processes whereby layering, sorting and shearing can result during till deposition. These features were often observed during the examination of the sampling pits and cut banks. The particle size distribution curves were typical for a coarse textured glacial till. A complete range of particle sizes was represented from coarse sand through fine clay (Figure 3). The geographic

Table 4

A summary of physical and chemical characteristics of IICk horizons derived from glacial till parent material.*

Pedon No.	Sample No.	Horizon	Depth (cms)	Textural Class	Est. % c.f.s. (by weight)	% $CaCO_3$ equivalent	pH ($CaCl_2$)	Moist Colour
L1	5	IICk1	35-60	Sil	21	42	7.0	10YR 6/3
	6	IICk2	70-110+	SL	64	60	7.1	10YR 5/2
L2	11	IICk1	24-45	SL	64	70	6.8	10YR 4/2
	12	IICk2	45-90+	SL	75	80	7.1	10YR 4/2
L3	18	IICk1	50-75	Sil	62	40	6.9	10YR 4/4
	19	IICk2	75-100+	SL	55	58	7.1	10YR 5/4
P1	25	IICk1	44-65	Sil	52	53	6.8	2.5Y 6/4
	26	IICk2	65-90+	SL	-	51	7.0	10YR 4/2
P2	30	IIBCk	25-50	L	50	11	6.8	7.5YR 4/4
	31	IICk	50-75+	SL	80	47	7.0	10YR 4/4
B1	35	IICk1	34-50	L	44	23	7.0	10YR 4/4
	36	IICk2	50-90+	SL	57	40	7.3	10YR 6/3
B2	40	IICk1	27-45	SL	71	49	7.1	10YR 5/4
	41	IICk2	45-90+	SL	67	55	7.4	10YR 6/3
B3	45	IICk1	14-40	L	55	52	7.1	10YR 4/4
	46	IICk2	40-80+	L	50	77	7.2	10YR 6/4

* See Appendix 1 for complete data.

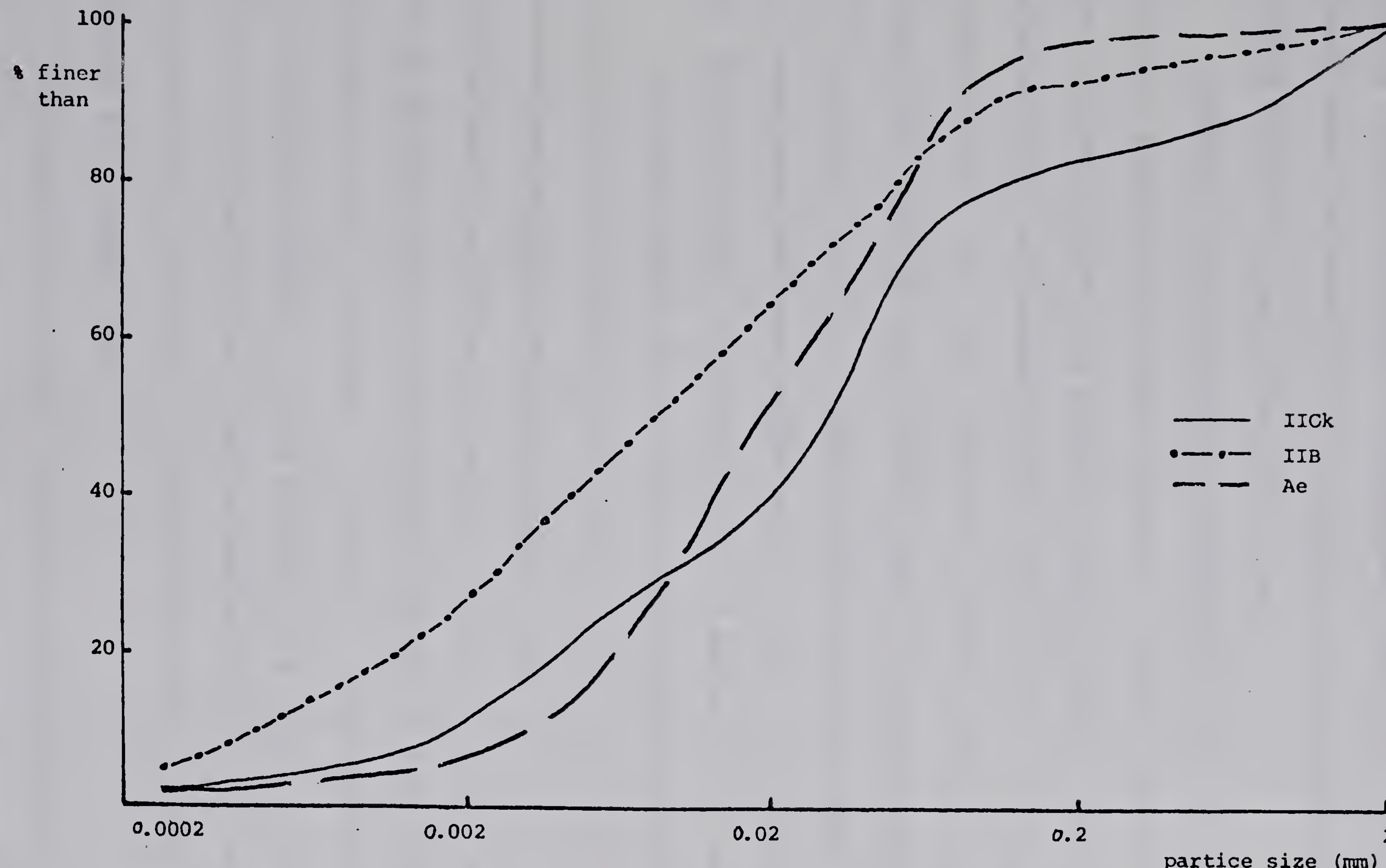


Figure 3

Particle size distribution curves from horizons formed in glacial till and eolian parent materials (L1 pedon).

location of the study area suggested that minimal transportation had taken place, and that the coarse texture was derived through the physical weathering of local limestone and sandstone formations. With only minor inputs of shale, the resulting till exhibited an extremely calcareous nature and rather low clay content (10 - 15%).

Results of the petrographic examination of the fine sand fraction are presented in Tables 6 through 9. Table 5 shows the distribution of mineral grains into specific gravity classes. Both the unweathered (IICk) and weathered (IIB) till horizons are listed. Data was generated from four sites selected for detailed study. Typically, till materials contained insignificant amounts of mineral grains with specific gravities < 2.50. In these samples the values ranged from 0 - 0.3%. Percentages have been rounded for the 2.50 - 2.72 and 2.72 - 2.92 groups, hence all values in the tables do not add up to 100 percent.

The data showed that the IICk horizons were dominated by fine sand sized grains with specific gravities of 2.72 - 2.92. This fraction represented predominantly carbonate minerals. The 2.50 - 2.72 grouping represented quartz and feldspar minerals. Note the relative decrease in quartz and feldspar with increasing depth from IIB to IICk horizons and the increase in 2.72 - 2.92 group (Figure 7). This displays the effect of carbonate removal. Heavy minerals (i.e. those with specific gravities > 2.92) made up less than one percent of the fine sand fraction of the glacial till. This was in agreement with data reported elsewhere (Pettapiece 1970, Rutter 1965).

Semi-quantitative lists of minerals grains from the < 2.50 grouping have not been presented in Table 6, however observations were made regarding the nature of this specific gravity separate. Some

Table 5

Distribution of fine sands from horizons formed within glacial till parent material into specific gravity groupings.

			Specific gravity groupings		
Pedon	Sample No.	Horizon	% 2.50 - 2.72	% 2.72 - 2.92	% > 2.92
L1	4	IIB	66	33	0.7
	5	IICk1	40	59	0.3
	6	IICk2	30	69	0.3
L3	16	IIB1	83	15	0.3
	17	IIB2	67	32	0.7
	18	IICk1	35	65	0.4
	19	IICk2	12	87	0.6
P2	30	IIBC	55	44	0.7
	31	IICk	28	71	0.3
B3	45	IICk1	20	80	0.3
	46	IICk2	16	83	0.3

opalaceous material was evident, as were numerous reddish weathering fragments which may, or may not, have been volcanic in origin, but appeared coated in some manner and were unidentifiable. Fragments of highly weathered glass made up the remainder of the suite. Pettapiece (1970) also observed volcanic glass within the till in his study area. It is speculated that this would have originated from an eruption $>$10,000 YBP. There was little quantitative or qualitative difference from one sample to the next, or from one sampling site to the next.

Table 7 lists those mineral grains comprising the 2.50 - 2.72 grouping. Quartz completely dominated each sample with lesser amounts of plagioclase and K-feldspar also present. Cryptocrystalline grains were abundant in the weathered till horizons and were presumed to be quartzitic. Carbonate mineral grains (most likely calcite) were found as well in this grouping in the IICk horizons. The quartz to feldspar ratio remained relatively constant throughout the samples.

The 2.72 - 2.92 grouping was almost entirely composed of carbonates. This was the largest specific density group within the IICk horizons. Again, cryptocrystalline grains were abundant, this time most likely carbonatic in nature. Trace amounts of mica, predominantly muscovite, (although some biotite was observed), also fell into this group.

Table 9 summarizes the heavy mineral suites. Opaque mineral grains were dominant in most samples. As well the lower IICk horizons showed an abundance of carbonate minerals. The separation at $>$2.92 specific gravity resulted in some of the heavier carbonate minerals (dolomite, magnesite) being included. The remainder of the suite was composed primarily of chlorite. This mineral, characterized by an

Table 6

Semi-quantitative groupings of mineral grains with specific gravity < 2.50.

Sample	Horizon	Volcanic glass (Unaltered)	Volcanic glass (Altered)	Quartz & Feldspars	Opal	Reddish weathered frag.	Others*
L1							
2	Ae	4**		1	1		1
3	Bf	4	3			2	
L3							
14	Ae	4	tr	2	tr		1
15	Bf	4	3	2		2	2
P2							
28	Ae	4		2	tr		1
29	Bf	3	3	1		2	2
B3							
43	Ae	4		1	1		1
44	Bf	4	3			2	1

* Others - Dominantly cryptocrystaline grains, lithic fragments which may or may not contain glass, carbonates, coated and/or weathered fragments, unidentifiables.

** 4 = $>$ 40%, 3 = 40 - 15%, 2 = 15 - 5%, 1 = $<$ 5%, tr = trace 1%.

Table 7

Semi-quantitative grouping of mineral grains with specific gravity 2.50 - 2.72.

Sample	Horizon	Volcanic Fragments	Quartz	Plagio-clase	K-spars	Cryptocrystal-line grains	Red Weather-ing Fragments	Carbonates	Others*
L1									
2	Ae	2**	4	3		2			1
3	Bf	2	3	2	tr	3	3		2
4	IIB	tr	4	—— 2 ——		2	2		2
5	IICk1		4	—— 2 ——		1	1	2	2
6	IICk2								
L3									
14	Ae	2	4	3	tr	2			2
15	Bf	2	4	2	tr	2	2		2
16	IIB1	1	4	1	1	2	2		2
17	IIB2		4	1	tr	2	2	tr	2
18	IICk1	tr	4	—— 2 ——		3	1	1	2
19	IICk2		4	—— 1 ——		2	tr	2	1
P2									
28	Ae	2	4	3	tr	1			1
29	Bf	2	3	2		3	3		1
30	IIBCk	tr	4	—— 1 ——		1	1		2
31	IICk2		3	1	1	1	1	2	1
B3									
43	Ae	3	4	3		1			2
44	Bf	1	3	1	tr	2	3		1
45	IICk1		4	1	tr	2	1	1	1
46	IICk2		3	1		2	1	3	2

* Others - lithics and secondary cemented grains of variable mineralogy, coated grains.

** 4 = > 40%, 3 = 40 - 15%, 2 = 15 - 5%, 1 = < 5%, tr = trace.

Table 8

Semi-quantitative groupings of mineral grains with specific gravity 2.72 - 2.92.

Sample	Horizon	Volcanic Fragments	Feld-spars	Pyroxenes & Amphiboles	Carbon-ates	Cryptocrystal-line grains	Red Weather-ing Fragments	Mica (predominantly muscovite)	* Others
2	Ae	2**	2	4	tr	3	tr	1	1
3	Bf	1	1	1		4	2	1	2
4	IIB				tr	4	3	1	2
5	IICk1		tr		4	3	1	tr	2
6	IICk2				4	2	1	1	1
14	Ae	2	2	4	tr	2		1	2
15	Bf								
16	IIB		1		tr	4	2	1	2
17	IIB2		1	1	4	3	tr	1	2
18	IICk1		1	1	4	3	tr	1	2
19	IICk2		1	1	4	2		1	2
28	Ae	2	1	4	1	1	tr	1	2
29	Bf	1		2	2	3	3	2	1
30	IIBCk		tr	tr	3	3	2		1
31	IICk		tr	tr	4	2	tr		1
43	Ae	2	2	4	tr	2	1	2	
44	Bf					3	4	tr	1
45	IICk1		1		4	2		1	2
46	IICk2		tr		4	2			1

* Others - opaques, chlorite, lithic fragments (may or may not be of volcanic origin) which often contain muscovite & feldspar. Cemented grains, coated grains, heavy minerals.

** 4 = $>$ 40%, 3 = 40 - 15%, 2 = 15 - 5%, 1 = $<$ 5%, tr = trace.

Table 9

Semi-quantitative groupings of mineral grains with specific gravities >2.92.

Sample	Horizon	Volcanic Fragments	Pyroxenes	Amphi-boles	Zircon	Chlorite & Chloritoid	Opaque	Iron oxide coated grains	Carbonates	* Others
2	Ae	2**	4	2			2			tr
3	Bf	2	4	2	1		2	2		1
4	IIB	tr	2	1	2	3	3	1	1	2
5	IICk1	tr	2	1	2	3	3	1	1	2
6	IICk2		1	1	1	3	3	1	3	1
14	Ae	1	4	2			2			1
15	Bf									
16	IIB1	1	2	1	1	3	4	2		1
17	IIB2		2	1	1	3	4			
18	IICk1		2	1	1	3	3		2	
19	IICk2		1	1	1	2	4	1	4	1
28	Ae		4	2			2			1
29	Bf		3	2		1	3	2	1	1
30	IIBCk									
31	IICk	tr	1	1	1	3	4		2	1
43	Ae	1	4	3			2			1
44	Bf	1	4	2	1		2	1		1
45	IICk1	tr	3	2	1	2	3	2		1
46	IICk2	tr	1	2	1	3	4		2	1

* Others - garnet, rutile, clinozoisite, tourmaline, lithic fragments, and unidentified accessory minerals.
** 4 = $>$ 40%, 3 = 40 - 15%, 2 = 15 - 5%, 1 = $<$ 5%, tr = trace.

anomalous blue birefringence, was most useful in separating the origin of parent materials. It was not present in the heavy mineral suites of the upper solum. Lesser amounts of hornblende, pyroxene and a trace of chloratoid were also present. There appeared to be some variation in amphibole composition. Their structure permits some flexibility of ionic replacement which may produce a wide variety of chemical compositions in this mineral group. Pleochroic colour variation seemed to indicate hornblende was trending towards (decreasing Al content) the tremolite-actinolite group. The pyroxene content increased higher up in the profile, and as in the case with sample 45, indicated mixing with the surficial surface material (in which hypersthene dominates) had taken place. Zircon and tourmaline reported as the dominate non-opaque heavy minerals in till suites elsewhere (Rutter 1965, Pettapiece 1970) were present here in only trace amounts.

Figure 4 shows the x-ray diffractogram of the coarse clay (0.2 - 2.0 μm) fraction from a IICk2 horizon after pretreatment with Na-acetate to remove carbonate material (see materials and methods, Chapter 3). The patterns are representative of those obtained for all IICk horizons. The clay mineralogy appeared identical at all sites. The diffractograms displayed sharp, discrete peaks and low background. There was no response to solvation or heat treatments. These patterns were interpreted as representing a clay fraction composed of dioctahedral mica and chlorite. Further treatment with HCl for the selective dissolution of chlorite, revealed a trace of kaolinite present as well. There was very little to no amorphous material present within the sample. Analysis for K_2O showed the mica content in this sample to be about 50%. Typically, the coarse clays in the unweathered till had low CEC

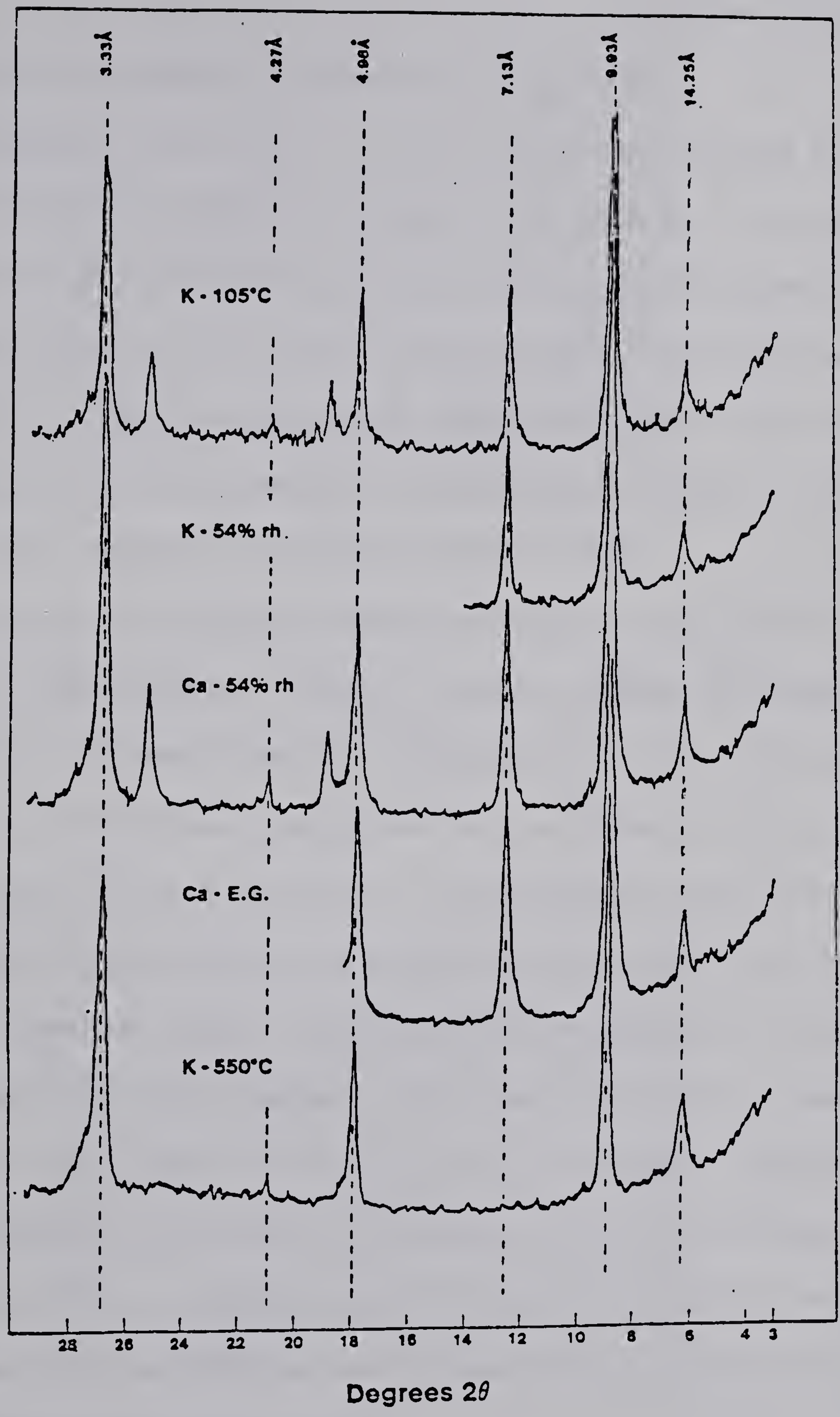


Figure 4

X-ray diffractogram of the coarse clay fraction (0.2 - 2.0 μm) from a IICk2 horizon, L1 pedon.

(30 me/ 100 gm), and surface area (110 m^2/gm). A detailed discussion of clay mineralogy and weather is presented in Chapter 3.

Observations made of the glacial till in thin section provided micromorphological characterization. Soil fabrics of the till parent material varied with texture. Fabrics have generally been described as porphyric, or, where they became exceedingly vughy, as granoidic-porphyric. Where considerable sorting had taken place, and the ratio of coarse to fine materials is much greater, fabrics of the chitonic and iunctic sequences resulted (Sleeman 1978).

The process of carbonate removal resulted in a variety of features observed in thin section. Figure 5 shows a narrow, horizontal planar void exhibiting cutanic material through its length. The cutanic material, based on birefringent qualities, is most likely to be carbonate precipitated in the void from solution. The carbonate would have originated through the dissolution of calcite and dolomite found within the soil matrix (Dumanski 1970). The dark brown staining is possibly residum associated with this process. While the solubility of these minerals is low in pure water, within the soil environment, dissolution is often accelerated by the addition of biogenic CO_2 to soil water (Salomans and Mook 1976). Calcitans may be a common feature of soils with high carbonate content (Brewer and Sleeman 1969), although they were rarely observed within these soils.

A more common observation was like that shown in Figure 6. It is thought that under most soil conditions carbonate solubilization and recrystalization reoccurs cyclicly with $CaCO_3$ reprecipitating (Rostad and St. Arnaud 1970, McKeague and St. Arnaud 1969). Hydrated $MgCO_3$ formed from dolomite weathering is highly soluble and thus readily

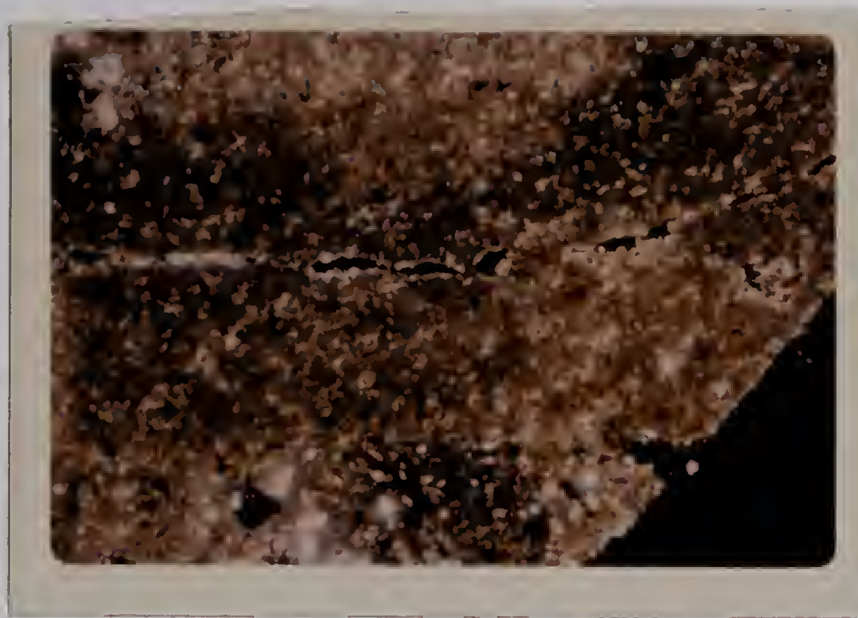


Figure 5

Void calictan. Thin section under crossed nicols. Cutanic material, apparently calcite, distributed along walls of a planar void within the IICk2 horizon L3 pedon. 20x.

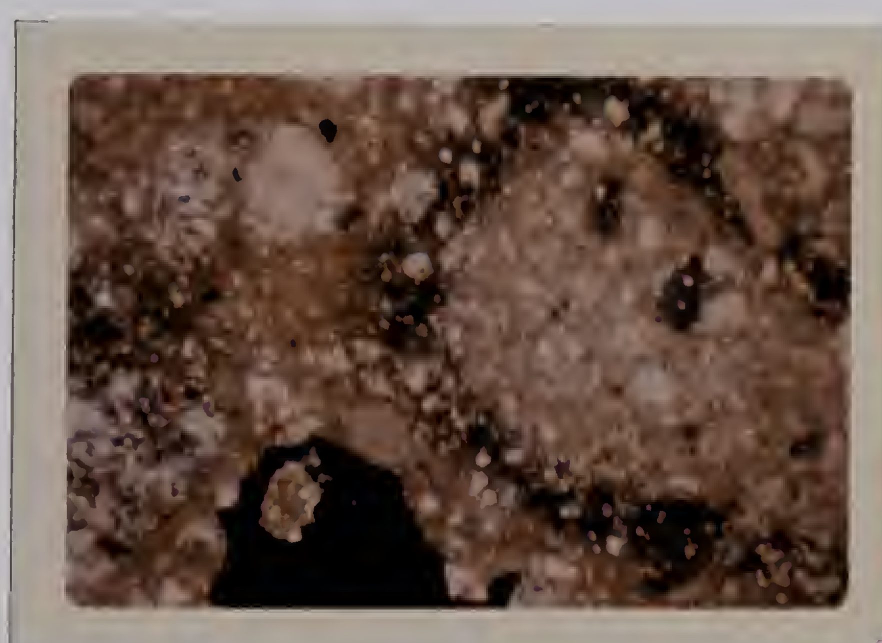


Figure 6

Quasicutan. Thin section under crossed nicols. A subcutanic feature associated with the solubilization and movement of carbonate materials. 20x.

leached. Its solubility product is such that it is unlikely to exist in equilibrium with calcite in the soil (Raad and Protz 1974). Hence soil carbonates may either be removed from, or be infused into, the matrix depending on soil moisture conditions. The quasicution seen in Figure 5 is thought to be a result of these processes, although the exact genesis of these subcutanic features is not well understood (Brewer 1976).

Limited occurrences of either banded or isobanded fabrics were observed with the calcareous parent materials. While certain zones of "micro platey" structure may be assumed to result directly from deposition or movements of the soil mass sometime afterward, other features must have resulted from pedological processes. Plasma concentrations within structural units at depths greater than one meter within the L1 pedon indicated that pedogenic processes are active (have been active) to considerable depth with the IICk horizons.

In summary, data generated from the various chemical, mineralogical, and thin section analysis, resulted in the following conclusions. The glacial till, inherently heterogeneous in many properties ($CaCO_3$ content, texture, colour), exhibited uniform sand and clay mineralogy within all samples and at all sites. Thin section analysis gave direct visual evidence of carbonate solubilization and redistribution within the soil matrix. Pedogenic processes were seen to be active deep within IICk horizons. Large changes in texture over short distances (i.e. sand and clay lenses) and "platey" macrostructures observed in some exposures were undoubtedly inherited features related to the mode of deposition and/or subsequent reworking of the deposit.

<u>Characteristics of the silty surficial parent material</u>

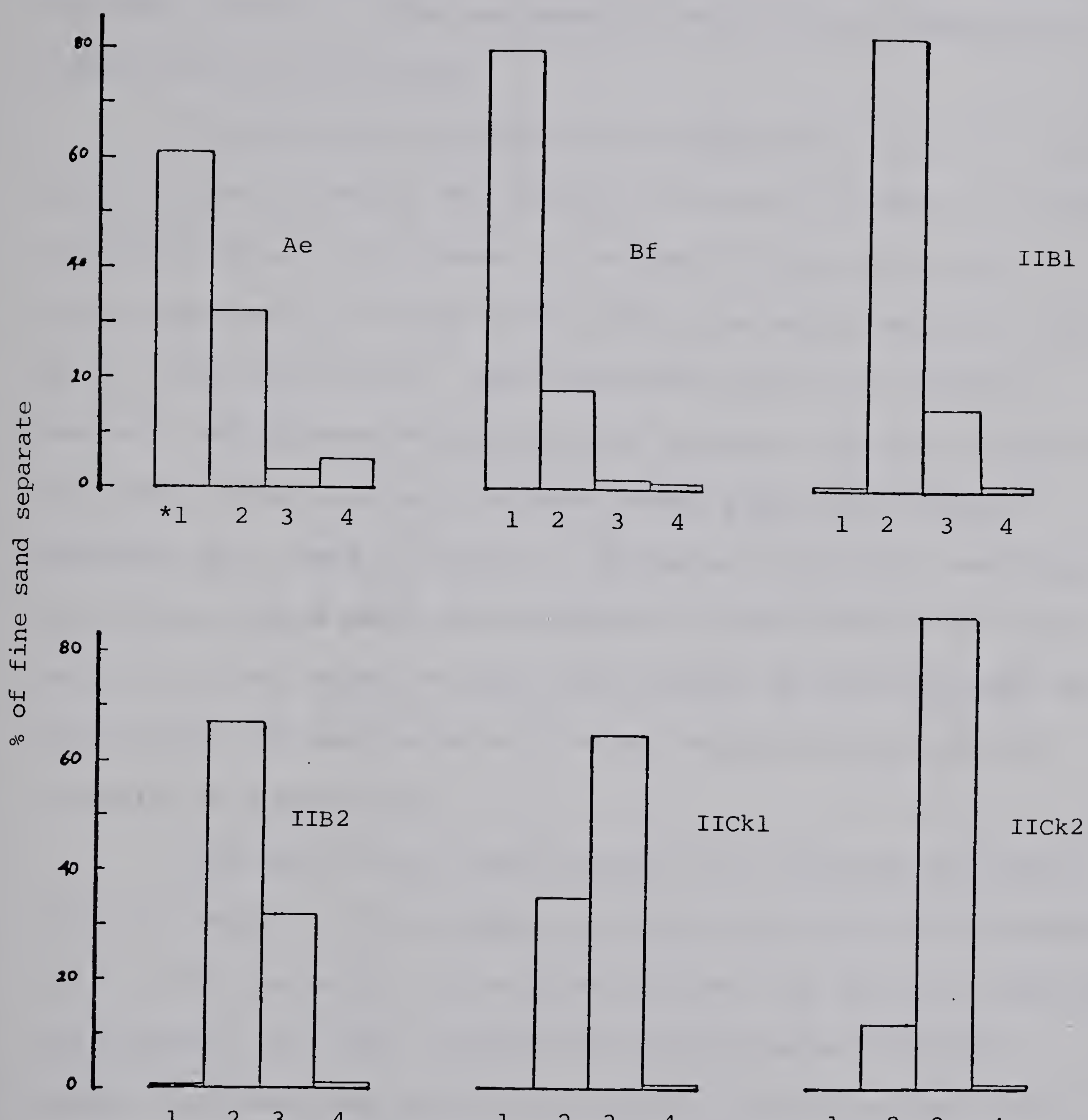
The surficial parent material exhibited a distinct morphology and was readily distinguished from the underlying glacial till in the field. However, its exact mineralogy, and mode of deposition was not known. The literature review indicated that locally derived windblown sediment, and/or volcanic ash from a variety of sources, may have comprised this upper parent material.

Routine analysis, particularly particle size distribution, revealed the loessial nature of the surface material. The sand mineralogy was significantly different from that of the till, and indicated a volcanic origin for much of this material. Particle sizes were dominated by silts and fine sands, with almost no coarse sand and very few coarse fragments. Clay content was generally low for horizons formed within this material. Bulk densities were less than 1.0 gm cm^{-3}. The particle size distribution curves were steeply sloping, and the mean diameter of the particles lay in the coarse silt range (see Ae horizons in Figure 3). These are all properties characteristic of loessial materials (Johnson and Beavers 1959, Hutchenson and Bailey 1965, Khangerat et al 1971, and Souster et al 1977). However this evidence alone cannot be used to prove the eolian origin of this silty material. Stratigraphic evidence would rule out the possibility that this is a lacustrine deposit. The uniform thickness and the observations of this same material extending into the alpine areas (both in the study area and elsewhere) support the hypothesis of eolian deposition rather than this being of fluvial or lacustrine origin.

Fine sands were investigated in the same manner as those from the glacial till. Figure 7 is a histogram respresenting the distribution of fine sand sized grains into the various specific gravity groupings through out one profile. The effects of a change in parent materials (I vs. II materials), plus, carbonate removal from a highly calcareous till (IIB horizons) are graphically exhibited. Note that the percentages depicted are of the fine sand fraction (0.05 - 0.25 mm) and not the entire fine earth sample. The most obvious feature is the dominance of the $<$ 2.50 specific gravity group in the surface material. Note the proportion of heavy minerals in the Ae horizon relative to that in all other horizons. This unusual distribution of specific gravity groups resulted from an abundance of glass fragments and phenocryst minerals derived from volcanic ash.

The reader is once again referred to Tables 6 through 9. The $<$2.50 grouping is composed almost entirely of volanic fragments. The majority of this is glass material. These appear clean and unaltered in the Ae horizons, rather weathered and somewhat altered in the Bf horizons. The category listed as reddish weathering fragments represented coated grains, presumably glass. Most horizons contained a minor amount of weathered grains, glass encrusted plagioclases, and a trace of biogenic opal.

The 2.50 - 2.72 specific gravity grouping was dominated by quartz. However the plagioclases were a major component as well. Although some overestimation of quartz was inevitable, the job of differentiating it from the plagioclase minerals was less difficult than in the till parent materials. Well developed embayment features, abundant albite twinning, and glass encrustations, made identification



*1. < 2.50; 2. 2.50 - 2.72 3. 2.72 - 2.92 4. > 2.92.

Figure 7

Histogram showing the distribution of fine sands from major horizons in a luvisolic-like profile (L3 pedon) into specific gravity classes.

by optical properties relatively precise. While many of these feldspar minerals were glass encrusted, the classic zoning reported by Westgate and Smith (1967) and Dudas and Harward (1975b) was not observed in these fine sand sized grains.

As the surface materials are carbonate free, the 2.72 - 2.92 specific gravity grouping was reduced to very much a "catch-all" category as seen in Table 8. The reader is reminded that this group makes up only a very small percentage of the entire fine sands, relative to this group in the IICk samples. Glass encrusted pyroxene and amphibole minerals, and cryptocrystaline grains of uncertain composition dominated the suite. Minor amounts of volcanic glass, plagioclase feldspar, muscovite and a trace of carbonate, rounded out the mineral assemblage. As carbonate grains would not be expected to remain within the surface material for any length of time, their presence in the Ae horizons (and not the Bfs) indicated minor local eolian additions to be presently occurring in the study area.

The heavy mineral suite was distinctly different from that of the till (Table 9). The pyroxenes, primarily hypersthene (orthopyroxene), and to a far less extent augite (clinopyroxene), are the major components. The amphibole hornblende, unidentified glass encrusted materials, opaques, and occasional exotics (i.e. others) make up the remainder of the assemblage.

It was clear that not only quantitative but very significant qualitative differences existed in the mineral suites between the glacial till and the silty surface material. The presence of abundant glass fragments, encrusted mineral grains, embayed plagioclases, and the high

proportion of pyroxene and amphibole minerals established without doubt the volcanic influence within the surface parent material. However, at the same time, the presence of quartz and K-feldspars revealed that this deposit was not composed entirely of volcanic material but that local detritus was included as well. Having established that much, restatement of the multiple working hypothesis, and a discussion of each of the hypothesis would now seem appropriate.

It was stated that the soils investigated at Sunwapta Pass have formed within a bimodal system of parent materials whereby a glacial till was capped with:

1. A well sorted ablation deposit, reworked by water during deposition or at sometime shortly thereafter, and exhibiting similar mineralogy to the underlying till.

2. A locally derived eolian material composed of detritus mineralogically similar to the underlying till.

3. A mixture of volcanic ash and local detritus which was mineralogically distinct from the underlying glacial till.

Hypothesis 1 could be rejected based on the results of particle size distribution, petrographic analysis and stratigraphic evidence. Likewise, hypothesis 2 was rejected based on mineralogy of the deposit. Hypothesis 3 was best supported. The deposit appeared to be comprised of both local detritus (presumably windblown) and volcanic ash.

The acceptance of this hypothesis however lead to further questions. It was known that the volcanic ash was deposited as a result of a number of discrete depositions between 6,600 and 2,300 years ago (Westgate and Dreimanis 1967). It was not known however, whether the local material originated from continuous accretion or was deposited in

episodal fashion since deglaciation. Based on field morphology, this surficial parent material appeared homogeneous, and the preservation of discrete ash and/or local loess layers was not evident. Table 10 provides a more detailed quantitative look at the mineral suites of the two horizons formed within this material. Note the relative increase in glass between the Ae and Bf horizon. At the same time there was a 10 fold reduction in heavy minerals (phenocryst minerals). Van Ryswyk (1969) found the same phenomenon. That is, the higher the glass content, the lower the phenocryst mineral composition. He suggested wind winnowing and drifting following deposition to explain the inconsistent ratios of glass to phenocryst minerals in horizons of alpine soils. Qualitative differences in the mineral suites (i.e. slight decrease in pyroxene, and increase in opaques) within the upper solum are outlined as well.

The literature was reviewed for the heavy mineral composition of the various known ash deposits. Somewhat mixed assemblages were reported, and some geographical variations were evident (Westgate and Dreimanis 1967, Westgate et al 1970, Nasmith et al 1967, Crandel et al 1962). In summary, the St. Helen's Y ash was characterized by cummingtonite and an abundance of hornblende; Mazama by hypersthene; and Bridge River by hypersthene and much lesser amounts of hornblende.

Pettapiece (1970) reported a heavy mineral suite in surface horizons of soils in the North Saskatchewan River valley, and, that it most closely resembled the Bridge River phenocryst suite. Pettapiece's observation supported a similar conclusion for this study. The absence of cummingtonite limited the possibility of the presence of St. Helen's Y ash within the parent material. Mazama ash was considered present, although

Table 10

Specific gravity distribution of fine sands within the surficial materials at the Sunwapta Pass study area.

	< 2.50	2.50 - 2.72	2.72 - 2.92	> 2.92
Pedon L1				
Ae	56	34	4	6
Bf	70	26	3	0.5
Pedon L3				
Ae	61	32	3	5
Bf	80	18	1	0.6
Pedon P2				
Ae	67	25	3	6
Bf	80	17	2	1

Light minerals: Glass fragments appear more weathered and more often coated with ferrugeneous material in Bf relative to Ae.

Heavy minerals: Ae - 60-70% pyroxene, 15% amphibole, 10% opaques.
Bf - 40% pyroxene, 12-15% amphibole, 18-25% opaques.

no discrete deposit was observed. There did not appear to be evidence of a lithologic break within the upper parent material (i.e. between the Ae and Bf horizons), although there was a slight increase in the relative proportion of hornblende with depth within the upper solum at three sites (Table 10). It was concluded that mixing of ash and loess layers must have taken place, producing the relatively homogeneous (mineralogically) surficial parent material observed in this study. Tree throw, (Dudas and Harward 1975b), mass wasting, and perhaps faunal activity would all be probable mechanisms producing periodic disruption of the surface materials and incorporation of coarse fragments into the Bf horizon.

To complete the characterization of the silty surficial material, the clay mineral assemblage and micromorphological features were investigated in the same fashion as was done with the glacial till parent materials.

Clay fractions of horizons within the upper solum were dominated by amorphous material. Clay was limited in the horizons, especially fine clay, which generally made up less than one percent of the fine earth fraction. Interpretable patterns could be obtained from most Ae horizons without pretreating the sample. However the effect of increased amorphous materials as a result of weathering in the Bf horizons, along with that of volcanic origin, yielded diffratograms without characteristic peaks. This was remedied to some extent by treating the samples with acid ammonium oxalate. The problem of obtaining interpretable patterns might be explained in terms of both chemical and physical properties. Preferred orientation of the phylosilicate clay minerals may not have been achieved due to the presence of amorphous particles

within the sample.

The fact that clay minerals were present at all, provided further evidence for the mixed origin of the surface parent material (hypothesis 3 of the multiple working hypothesis). The presence of phylosilicate minerals was used as a method by Dudas and Harward (1975b) of determining the degree of mixing of underlying paleosol material with a surface layer of Mazama ash.

Figure 8 illustrates the response of the fine clay separate from the Ae horizon of pedon L1 to various solvation and heat treatments. Most obvious, was the lack of discrete, well developed peaks and low background that was observed in Figure 4 for the till sample. Here the pattern was characterized by numerous diffuse peaks with associated shoulders and plateaus. These patterns represent weathered clays, with the resulting production of a chloritic intergrade mineral (or randomly interstratified mineral). The mica had been largely depotasified and vermiculite formed as a result. This in turn had been intercalated with Al-hydroxy material which was partially polymerized within the vermiculite interlayers. The Al-hydroxy material involved was largely produced as a result of the weathering of amorphous volcanic materials (Beke and Pawluk 1971, Pettapiece and Pawluk 1972, Pawluk and Brewer 1975b). The mica content was down to only 26%, i.e. about half what was present within the till sample. Chlorite appeared to be entirely lacking. Discrete vermiculite, amorphous material, and chloritic intergrades comprised the clay fraction.

The changes seen in soil fabric were no less dramatic than those in the clay mineralogy. The main feature of the upper solum, especially the Ae, was an overall isotropic character. Locallized zones

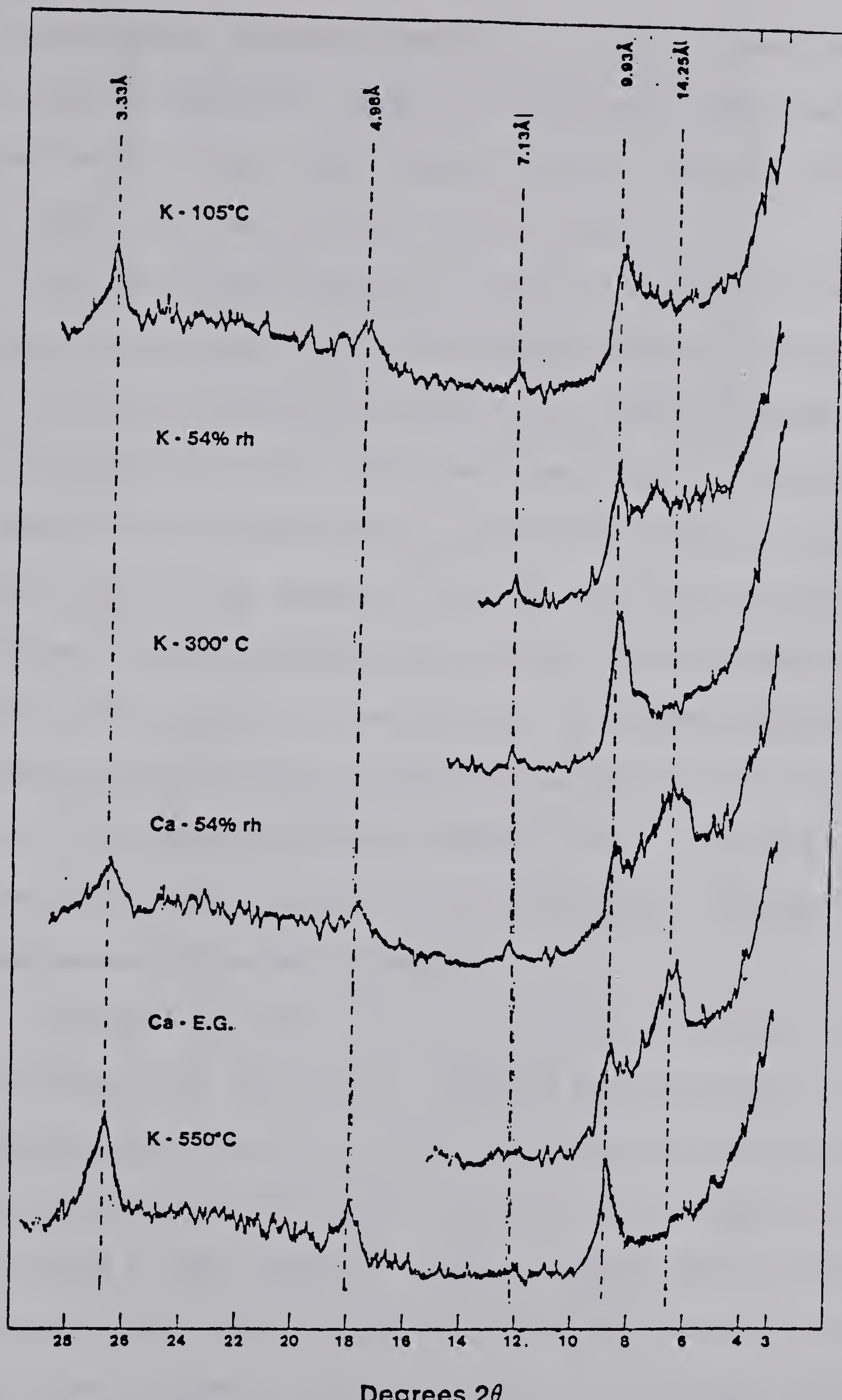


Figure 8

X-ray diffractogram of the fine clay fraction ($<0.2\mu m$) from an Ae horizon. (L1 pedon).

showed isotic plasma, although generally a silasepic plasmic fabric (Brewer 1976) was observed. Depth to a truly sepic fabric varied, and was a function of mixing. The mixing of strongly anisotropic materials into the upper solum occurred in a patchy fashion.

The most notable feature of the micro structure of the upper solum was the considerable banded and isobanded material present (Dumanski and St. Arnaud 1966, Brewer and Pawluk 1975). The true banded fabric (i.e. a plasma concentration within the upper portion of structural unit) seemed to be best displayed at some depth within the horizons rather than right at the surface. Root channeling and to a lesser extent faunal activity, tended to disrupt this fabric, resulting in the production of more granoidic-like fabrics. The finest examples of banded fabric existed within the lower Ae horizon of the L1 and P2 profiles. There existed a general tendency for all structural units within the eolian parent material to have horizontal orientation, even if plasma concentrations were lacking.

Figures 9 through 12 show the various fabric types found within Ae horizons of these soils. Figure 9 shows the typical, well developed, parallel orthojoint planar voids between structural units. Plasma concentrations at the top of these units were largely absent. Figure 10 shows a more fragmented isoband (Dumanski and St. Arnaud 1966) fabric, probably the result of plant roots as indicated by the presence of large organic fragments within the matrix. On the other hand, more rounded features as shown in Figure 11 would likely have been produced by faunal activity (Pawluk and Brewer 1975b). In Figure 11 the incorporation of humic material into these matrigranoidic units can be seen. Figure 12 shows an example of classic, well developed, banded fabric

Figure 9

Isoband fabric. Thin section under partially crossed nicols. Typical fabric of the Ae horizons formed within loess material. 20x.

Figure 10

Weakly banded graonidic-fragmoidic fabric. Thin section in plain light. Disrupted fabric resulting from plant root activity. 20x.

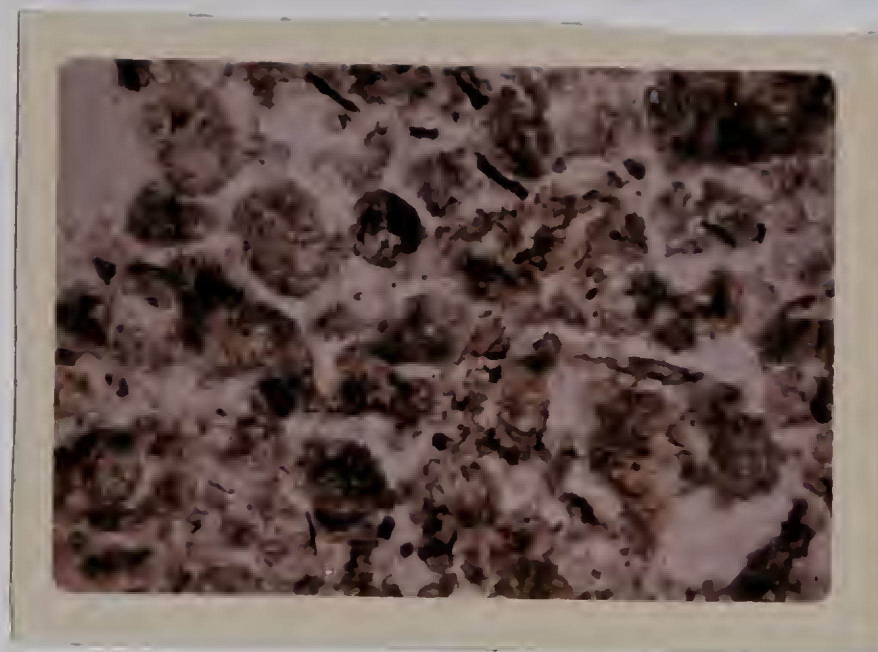


Figure 11

Humi-matrigranoidic fabric. Thin section under partially crossed nicols. An example of reorganization of materials by soil fauna. 20x.

Figure 12

Banded fabric. Thin section in plain light. An example of classic banded material from lower Ae horizon, P2 pedon. 20x.

from the lower Ae horizon of the P2 pedon. Two review articles, one by Dumanski (1970), the other by McKeague et al (1973) provided background on the development of these banded fabrics in Canadian soils. Freezing and thawing, and the development of ice lenses was thought to produce the horizontal plate-like structures. Wetting and drying was considered to be the primary process in development of the plasma concentrations as seen in Figure 12. These were largely restricted to Ae horizons, although banded fabrics have been reported within the parent material of arctic (Brewer and Pawluk 1975) and subarctic soils (Pawluk and Brewer 1975a).

Unlike Pettapiece's (1970) finding that well banded fabrics (of Ae) were associated with well developed Bt horizons, there appeared to be no connection between the nature of the B horizon and the soil fabric in the A. While the strongest banding occurred in the luvisolic-like profile from pedon L1, the Podzolic soil from pedon P2 also exhibited very strong banding.

A different structure was often observed in the Bf horizons. Rather than solely horizontally oriented structural units, aggregation of more rounded units resulted in an array of granoidic and banded granoidic fabrics. The Bf horizons also showed highly variable degrees of mixing with till material. In the L3 pedon, coarse fragments were found to within 7 cms of the surface, and as a result, a matrigranoidic fabric was found in the lower portions of the Bf horizon in this profile. Where there was no mixing, a fabric more like that seen in the Ae horizon (Figure 13) results. Here, one sees a good example of isobanded fabric. This tendency towards horizontally aligned units separated by orthojoint planar voids was seen in this example. However, an overall porphyric fabric was often found where this tendency was not exhibited.

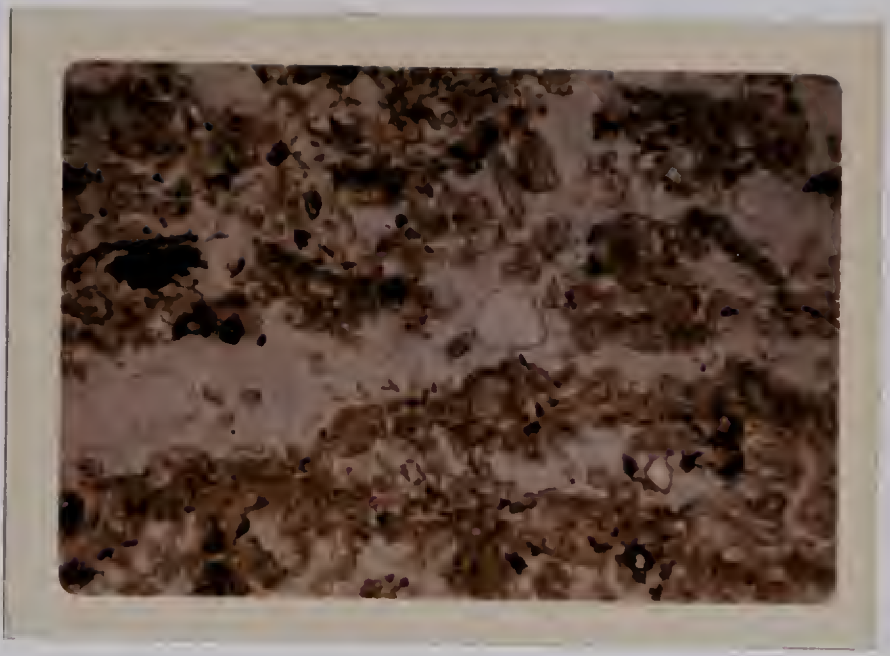


Figure 13

Isobanded porphyric fabric. Thin section in plain light. Typical soil fabric as seen in the Bf horizons. 20x.

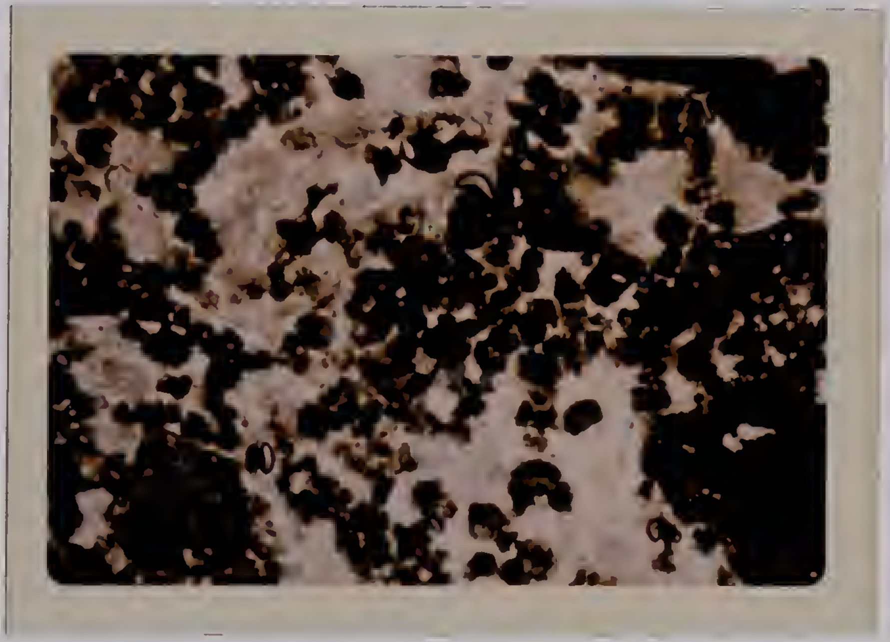


Figure 14

Phyto-humi granic units. Thin section in plain light. Small (<0.1 mm) fecal pellets and/or comminuted plant fragments found within the fabric of Bf horizon L3 pedon. 20x.

Note that the soil matrix was dominated by a complex of silt sized glass shards and minerals grains. The plasmic fabric was largely isotic.

Often features such as that shown in Figure 14 were found as well. This represents an area of intense faunal activity, dominated by what appears to be small (0.07 - 0.10 mm) fecal pellets. The incorporation of organic matter into humigranic units is the processes viewed here. Total C and N analysis showed a marked and constant increase within these B horizons. Obviously, not all the organic matter found in this horizon has evolved through illuviation in the classic sense of Podzolic B horizons. Much more faunal activity was observed in these Bf horizons than any other. Why this should be was not clearly evident, however, it demonstrated the vital role played by soil fauna, both in terms of humus production, structural reorganization, and elemental cycling. De Connick et al (1973) concluded that the early formation of Bf horizons involved polymorphic organic material (i.e. not having been previously solubilized) and undecomposed plant remains, being assembled into units typical for faunal and microfaunal activity, i.e. fecal pellets, pellets, aggregates and complex accumulations. There was no evidence here for illuviated solubilized organic matter associated with skeleton grains or void walls, as described elsewhere (Bjorklen and Jongerius 1973, McKeague et al 1969, McKeague et al 1973) for Podzolic B horizons.

Conclusions

Rather striking differences between the surficial parent material and the underlying calcareous glacial till were demonstrated. Sand mineralogy, clay mineralogy, micromorphology and particle size

distribution investigations lead to the conclusion that the two parent materials were of different origin and were mineralogically distinct from each other (Hypothesis 3). It was further concluded that the silty surficial parent material was composed of two volcanic ash deposits plus locally derived windblown sediments. Tree throw, mass wasting, faunal activity and subsequent reworking of the deposit by wind and/or water eliminated the presence of any discrete stratigraphic layers. The deposit was concluded to be mineralogically homogeneous.

The glacial till parent material was dominated by carbonate minerals and quartz. Cryptocrystalline mineral grains were abundant within weathered till horizons. It was concluded that this parent material was mineralogically uniform throughout the study area. Micromorphological observations lead to the conclusion that pedogenic processes were operative to depths well within the IICk horizons. Carbonate solubilization and redistribution were the major processes observed.

Chapter 3

GENESIS OF APPARENT TEXTURAL B HORIZONS FOUND WITHIN THE GLACIAL TILL PARENT MATERIAL

Introduction

The presence of an apparent argillic horizon (IIBt) within the soils of the upper subalpine zone at Sunwapta Pass (2,000+ meters asl) was considered unusual. This elevation was considered outside the normal environmental range of Luvisolic soils (See Chapter 1). This study was undertaken to examine, in detail, the B horizons in question, and attempt to elucidate their genesis.

The following multiple working hypothesis was used to direct this phase of the study. The IIB horizons, which showed striking increases in clay relative to horizons above and below, and strong to moderate subangular blocky structure, resulted from:-

1. The pedogenic dissolution of highly calcareous parent geologic material. That is, structural rearrangement, and change in the relative proportions of particle sizes, was due to the removal of carbonate minerals.

2. Classic lessivage processes with the formation of a true pedogenic argillic (Bt) horizon.

3. Non-contemporary soil forming processes i.e. the horizons were paleo features formed under different environmental conditions than exist today.

In order to test the hypothesis a number of investigations were undertaken and are reported here. The influence of carbonate removal from IICk horizons on particle size distribution was evaluated. Micromorphological features of IIB horizons were examined and described particularly in terms of pedologic features of clay movement and plasma

reorganization. Scanning electron microscopy (S.E.M.) was used to view ped exteriors from these same horizons. The clay fraction was analysed by X-ray diffraction (X.R.D.) and examined for qualitative changes in both luvisolic-like and Podzolic profiles.

Methods and materials

Particle size analysis of IICk horizons was conducted in a similar manner to that described in Chapter 2. However a subsample was treated with acid to remove carbonates. Numerous additions of 1N HCl were added to the soil and decanted until all indications of effervescence had ceased, and the pH of the suspension remained below 4.5 (Canada Soil Survey Committee 1978b). This sample was then subjected to the pipette procedure in exactly the same fashion as the others.

For X.R.D., clays were dispersed using a probe type ultrasonic vibrator following the method of Genrich and Bremner (1972). The sample was wet sieved through a 300 mesh sieve ($47 \mu m$) to remove sand. The clay ($< 2.0 \mu m$) was separated by gravity sedimentation and decantation to appropriate depths as calculated from Stokes Law (Jackson 1956). Where necessary, a step involving the removal of carbonate material was added. This involved treatment with Na-acetate buffered to pH 5.5 (Canada Soil Survey Committee 1978b) followed by further sonfication before clay separation. Fine clays were separated from selected samples using a centrifugation method as outlined by Jackson (1956). Slides were prepared from Ca and K saturated clays using the paste method of Theisen and Harward (1962). The bulk of the Ca-sat clays were freeze dried for later analysis. No pretreatment to remove organic matter was employed. Acid ammonium oxalate was used on Bf horizons in order to obtain interpretable X.R.D. patterns. The following treatments were run:

1. K-saturated clay, heated to 105°C and run at 0% relative humidity.

2. K-saturated clay heated to 105°C and run at 54% relative humidity.

3. K-saturated clay, heated to 300°C and run at ambient conditions.

4. K-saturated clay heated to 550°C and run at ambient conditions.

5. Ca-saturated clay run at 54% relative humidity.

6. Ca-saturated clay, solvated with ethelene glycol, and run at ambient conditions.

X-ray diffractograms were obtained with a Philips X.R.D. unit equipped with a curved crystal monochronometer and the use of Cu Kα radiation.

The freeze dried Ca-saturated samples were used in the following determinations. Surface area, following the procedure of Heilmann et al (1965), was derived. Cation exchange capacity (CEC) was determined by treating each sample with NH_4 acetate to effect cation exchange, then leached with isopropyl alcohol prior to steam distillation and the determination of absorbed NH_4^+. The K_2O content of each sample was obtained by HCl - HF dissolution of the clay followed by elemental determination for K by atomic absorption spectroscopy (Pawluk 1967).

Micromorphological descriptions were obtained from thin sections cut from impregnated monoliths as described previously. The terminology used to describe soil fabric was that from Brewer and Pawluk (1975) and Sleeman (1978); plasmic fabric and pedological features are described using that of Brewer (1976). Estimates of apparent illuvial clay were obtained following the procedure of McKeague et al (1978).

Ped surfaces were examined with a Cambridge 5150 scanning

electron microscope. Magnification of 50 to 1000x was employed. The peds were sputter coated with gold to a thickness of 150 Å to prevent charging of the sample.

Results and Discussion

Particle size analysis and the effects of carbonate removal.

The effect of removing large proportions of carbonate material from a glacial till was shown to result in a considerable change in the particle size distribution and hence texture of the sample. To examine this effect subsamples of IICk horizons were treated with HCl before standard pipette analysis. While this effect may be subtle when dealing with samples containing less than 10% $CaCO_3$ equivalent, those from Sunwapta, with equivalents often greater than 50%, showed some dramatic results. Figure 15 shows the result of carbonate removal from a till sample of 47% $CaCO_3$ equivalent. Note the two fold increase in total clay, four fold increase in fine clay, and a textural class change from sandy loam to loam. In response to these increases a proportionate drop in the percentage sand of the sample was seen. Figure 16 demonstrates the same pattern but the shift in distribution was even more pronounced with the higher $CaCO_3$ equivalent. One can see that if no pedogenic event occurred other than the simple removal of carbonate from the solum, a weathered horizon with three times the total clay, and ten times the fine clay, could result. Subsequent comparison of particle size distribution between a IIB, and a IICk horizon treated for carbonate removal, showed the two to be almost identical (Figure 16). Similar, yet somewhat less striking comparisons could be made within the other luvisolic-like profiles.

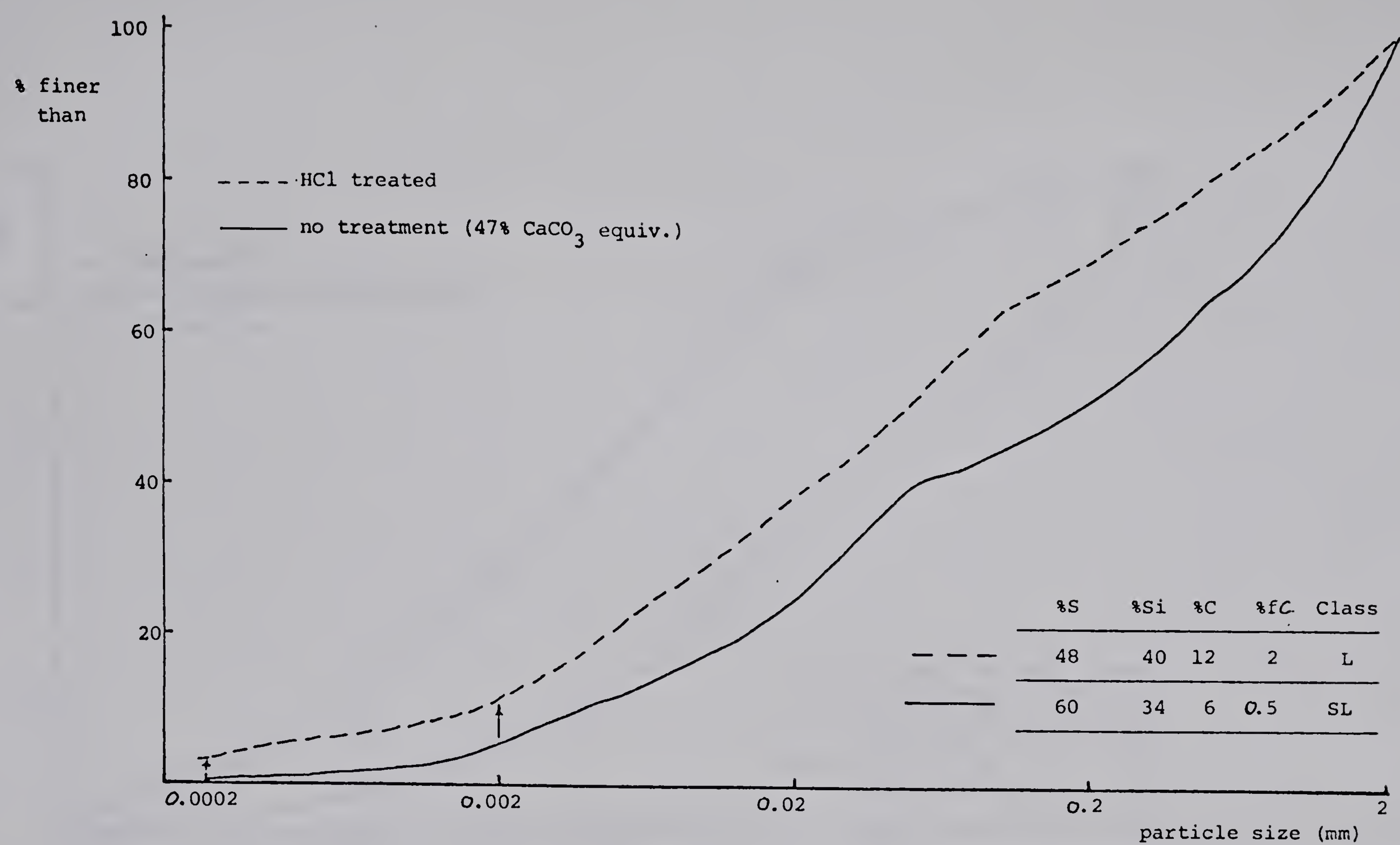


Figure 15

Change in particle size distribution as a result of removal of carbonate material from IICk2 horizon, P2 pedon.

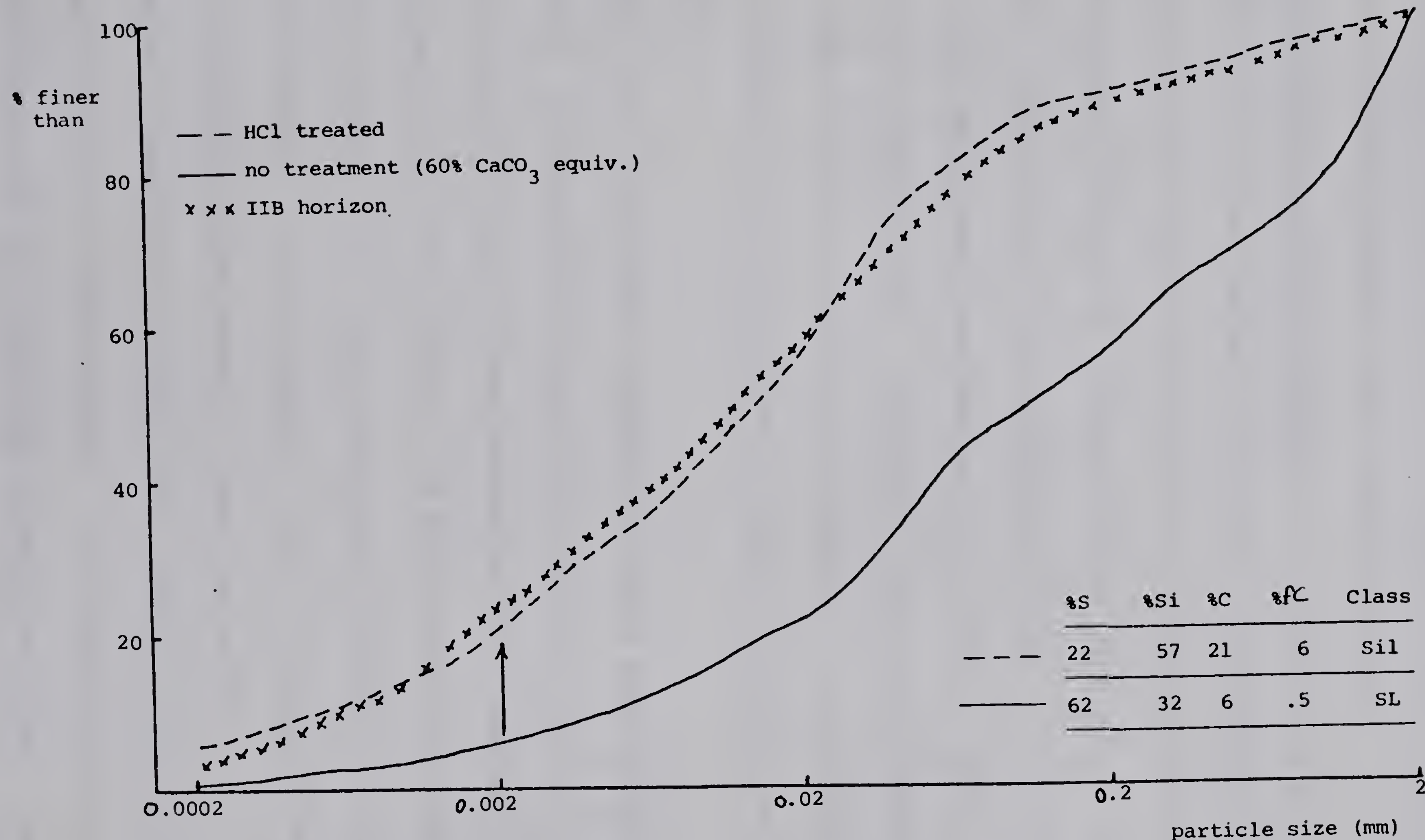


Figure 16

Change in particle size distribution as a result of carbonate removal from the IICk2 horizon, L3 pedon, and comparison with the IIB horizon.

The relative clay increases observed between the IIB and overlying horizons were attributed to the change in parent materials within the sola of the soils in the Sunwapta study area. The silty surficial material was concluded to be eolian in nature and thus inheritantly lower in clay size particles. It was therefore apparent that the clay "bulge", characteristic of luvisolic soils, could have been generated through processes other than lessivage.

Micromorphology of IIB horizons. At present, Bt horizons, diagnostic of soils in the Luvisolic order have been defined both in terms of particle size (the increase in clay relative to the eluvial horizon above) and oriented clay, either seen as clay skins or as seen in thin section (Canada Soil Survey Committee 1978a). In the initial field study, clay skins were described as being few to common and thin, on ped surfaces of IIB horizons. Therefore, the direct observation of the soil fabric of these horizons was thought to be the key to determining whether or not the process of clay illuviation was operative in these soils.

Two of the four pedons studied in detail were thought to possibly contain Bt horizons and have been referred to as IIB horizons within luvisolic-like soils. It was determined that generally, illuvial clay was lacking in the IIB horizons, and that papules and clay lamellae were often the most common pedological features within the fabric. The following is a discussion of the soil macrostructure and results of micromorphological study of these two soils.

Table 11 presents in summary form, some of the structural relationships observed in these horizons. The macrostructure was uniform through each horizon and was invariably subangular blocky. However,

Table 11

Relationship between structures as described in the field and in thin section.

Pedon	Horizon	Depth (cms)	Macro Structures	Micro Structures	Clay Skins	Cutanic Features	Estimated Illuvial Clay %
L1	IIB	17-30	moderate, medium subangular blocky to strong fine subangular blocky.	Upper portion - Porphyric to a granoidic porphyric intergrade fabric.	Common, very thin	Occasional, weakly, expressed neocutans.	0.3
			moderate, medium subangular blocky to strong fine subangular blocky.	Lower portion - Porphyric with a granoidic-fragmodic component.	Common, very thin	Diffuse, discontinuous void argillans.	0.7
	IICk1	30-50	strong, fine to medium, subangular blocky. Coarse platey in isolated zones.	Upper Portion - Plectic porphyic mixed fabric, some isolated chitonic components.	Common, very thin	Local patches of strongly separated and well defined yellowish red argillans, distribution is discontinous and limited.	1.0
L3	IIB1	20-35	Moderate, medium subangular blocky to strong; fine subangular blocky.	Upper portion - Weakly bonded fragmoidic and granoidic.	Common, thin to very thin	Rare, weakly oriented void argillans, diffuse neocutans.	0.4

Table 11 (continued)

Pedon	Horizon	Depth	Macro Structures	Micro Structures	Clay Skins	Cutonic Features	Estimated Illuvial Clay %
				Lower portion - granoidic and granoidic porphyric, very vughy.	Common, thin to very thin	Common, strongly oriented void argillans and papules. Variable thickness and distribution irregular, rare embedded grain cutans.	1.5
L3	IIB2	30-50	moderate, medium subangular blocky to strong, fine subangular blocky.	Lower portion - granic and granoidic porphyic sequence of fabrics.	few, thin	Occasional ferriargillans, papules and clay lamellae rare.	0.3
	IICk1	50+	weak, medium, subangular blocky.	Upper portion - granoidic porphyic fabric between numerous large lithic fragments.	very few, thin	ferrigeous neocutans associated with weathered lithics, rare papules.	0.4

when these materials are viewed in thin section, further subdivision is ususal, based on zones (Pawluk and Brewer 1975a) of fabric not seen in field observations. The strong, fine subangular blocky structure of the IIB horizons was unique. Often, one got the impression of an almost granular structure. In the IICk horizons, the structural units were larger, and in the case of the L1 pedon, plate-like structure was observed, likely a result of depositional influences. Often C horizons are considered to have amorphous structure, however these uppermost C horizons had undergone some weathering and there was some expression of pedality. The microstructure was usually porphyroskelic. That is, a dense fabric, often consisting of numerous irregularly shaped voids, with common larger skeleton grains embedded within the fine material (matrix). Around the walls of these voids and occasionally about skeleton grains embedded in the matrix, yellow clay material was observed.

Unlike the silty surficial materials which most often exhibited banded and isobanded fabrics, these horizons tended to exhibit vughy porphyroskelic or granoidic-porphyric intergrade fabrics. Such was the case within the upper portion of the IIB horizon from the L1 pedon. This weathered till showed weak vo-mosepic plasmic fabric, a sharp contrast to the generally asepic fabrics found in the upper solum. Occasional, weakly expressed neocutans associated with voids were present, becoming more common with depth. Ferrugenous zones and diffuse nodules were also present. Classic illuvial argillans were rare and total illuvial clay was estimated to be about 0.3% in the zone. This agrees with other worker's estimates of soils from the same location (McKeague, LRRI, Ottawa, personal communication). Beneath this, the fabric became

infused with a dense greyish-brown plasma, often masking any birefringence. The fabric was similar to the zone above, however a component of matrigranoidic and matrifragmoidic units was also present. Void argillans were present, although they were poorly separated from the soil matrix and were discontinuous. Neocutans were the dominant pedological feature (Figures 17 and 18), and were associated with the brownish plasma. Papules were generally observed embedded within the soil matrix, but occasionally, could be found associated with voids. They appeared strongly separated, showed continuous extinction, and were recognized by their bright yellowish colour. The total apparent illuvial clay was approximately 0.8%. Although higher than that in the upper portion of the IIB it was still less than the 1% required by definition for a Bt horizon.

The fabric of the uppermost portion of the underlying IICk1 horizon was also examined. Considerable sorting was evident (presumably a depositional feature) and fabrics of the chitonic sequence (Sleeman 1978) predominated (Figure 19). Again, the brownish plasma was evident. Patches of illuvial clay were common as discontinuous void argillans or skeleton grain cutons. It was estimated that about 1.0% apparent illuvial clay was present. Figure 20 shows a silty matran capping over a carbonate lithic fragment. The matran was coated by what appeared to be a good example of an argillan. This particular feature seemed to indicate that contemporary illuviation of clay was not restricted to carbonate free soil horizons. The micrograph was taken of the IICk2 horizon, well below the weathering front of carbonate removal.

Two IIB horizons from the L3 pedon were also examined. The upper IIB1 horizon was similar to that in the L1 profile. It also

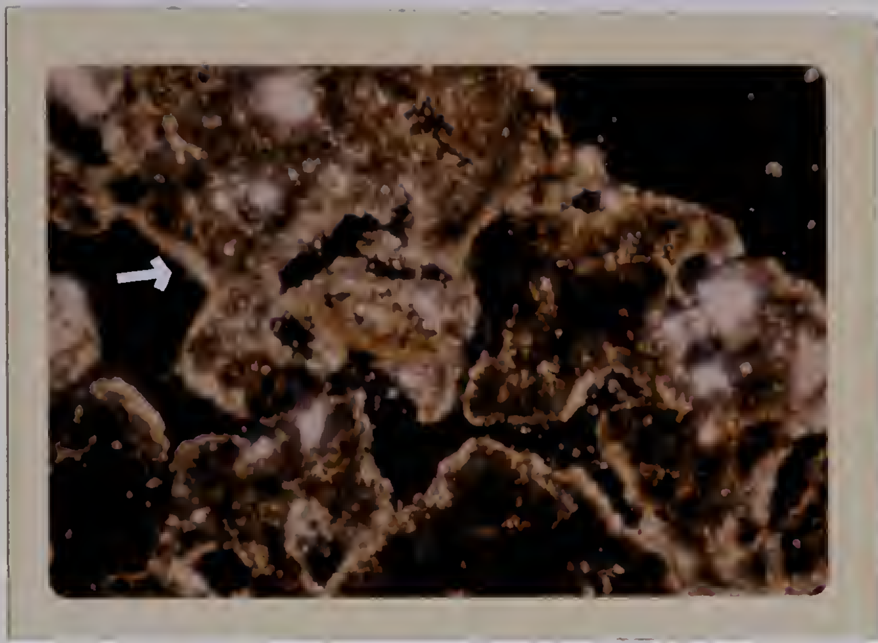


Figure 17

Neostrian. Thin section under crossed nicols. A strongly expressed neocutanic feature dominates the fabric (arrow). Note the dark plasma, ferrigenous nodules and matrigranoidic fabric. 20x.

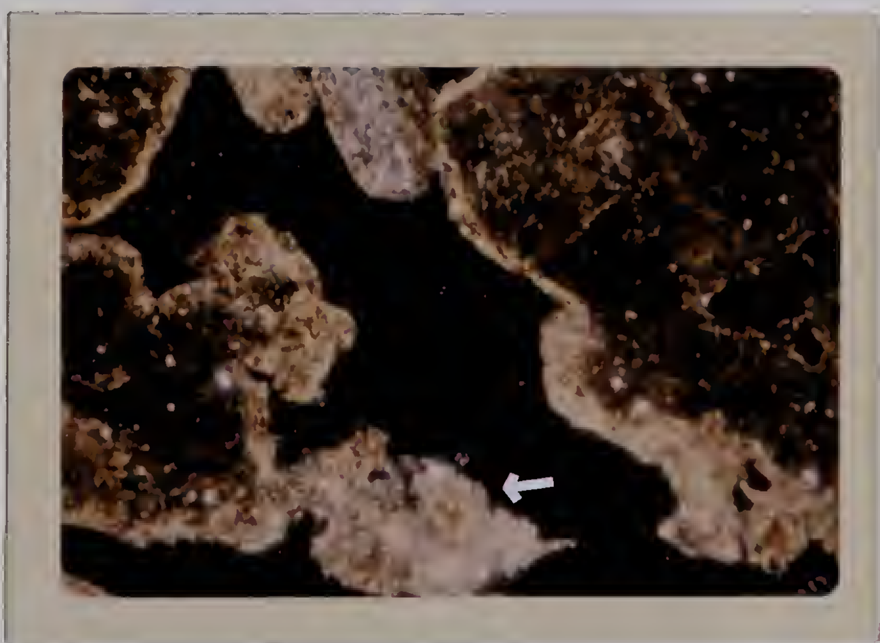


Figure 18

Neocutan. Thin section under crossed nicols. Close up view of similar feature to that seen in Figure 17. Note that the dark plasmic material is entirely absent from the s-matric in the bottom (arrow) center of the figure. 80x.

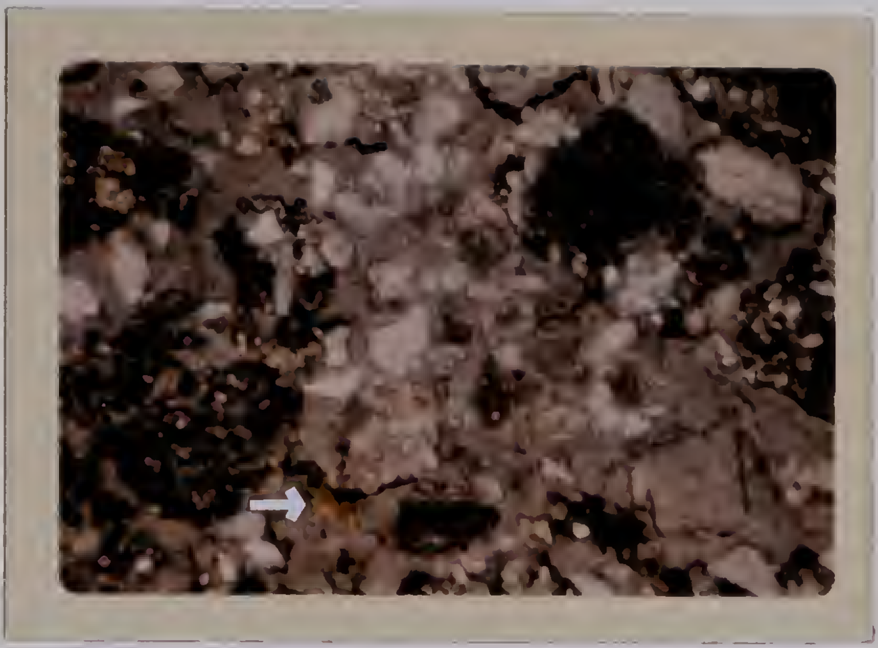


Figure 19

Sand lense exhibiting orthogranic fabric. This section under partially crossed nicols. Note the generally clean surfaces of the grains,although dark coatings on some grains create a chitonic fabric. The bright yellow papules (arrow) are typically found as isolated throughout. 20x.

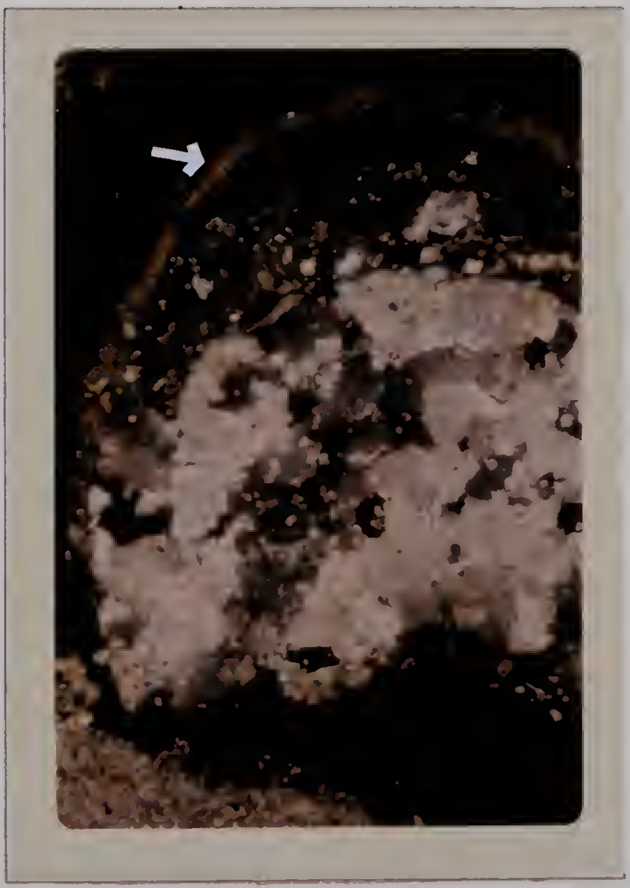


Figure 20

Silty matran capped by argillan (arrow). Thin section under crossed nicols. Note the complex cutanic structure associated with a large carbonate lithic fragment from the IICk2 horizon, L1 pedon. 20x.

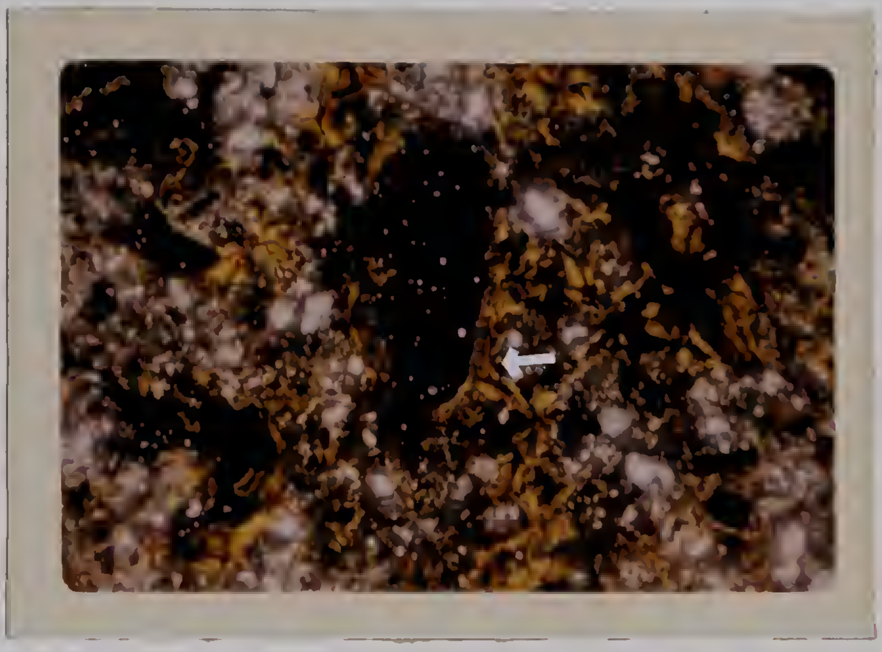


Figure 21

Vughy porphyroskelic fabric with strongly separated, distinct void argillans. Thin section under crossed nicols. Bright yellow illuvial material is distributed (arrow) about vughs and channels and shows strong continuous extinction. 20x.

Figure 22

Void argillan with strong laminar structure. Thin section in plain light. Note the complete in-filled voids and the incorporation of dark material into the argillan.

exhibited a weak vo-mosepic plasmic fabric. Once again brownish plasma predominated. It was estimated that less than 0.5% illuvial clay was present within this zone.

The lower portion of this horizon, IIB1, undoubtedly contained more illuvial clay than any other studied. Most existed as papules and clay lamellae. Some areas showed complete voids (Figure 21) infilled with bright yellow and reddish yellow, strongly separated, striated clay (Figure 22). Adjacent to these would be areas where none of the above was observed. The plasmic fabric was described as vo-skel-masepic, the overall soil fabric as matrigranoidic and vughy porphyroskelic. It was estimated that 1.5% apparent illuvial clay was present.

Beneath this was a second IIB horizon. While it was similar in its arrangement of materials, papules and lamellae were rare. As a result, point counts indicated that not more than 0.3% illuvial clay was present. The fabric was dominated by highly weathered lithic fragments giving an overall reddish colour to the soil matrix. Numerous neo-ferrans were associated with these fragments. A unique "sponge-like" fabric was observed, perhaps formed as a result of the dissolution of discrete carbonate mineral grains.

The uppermost portion of the IICk, horizon showed little illuvial clay, estimated at approxmately 0.4%. The few argillanic features that were present, were associated with void walls. Their distribution was patchy.

In a paper by McKeague et al (1978) the problems of measuring the amount of illuvial clay were discussed. In these soils, the biggest difficulty lay in separating subcutanic features from true argillans

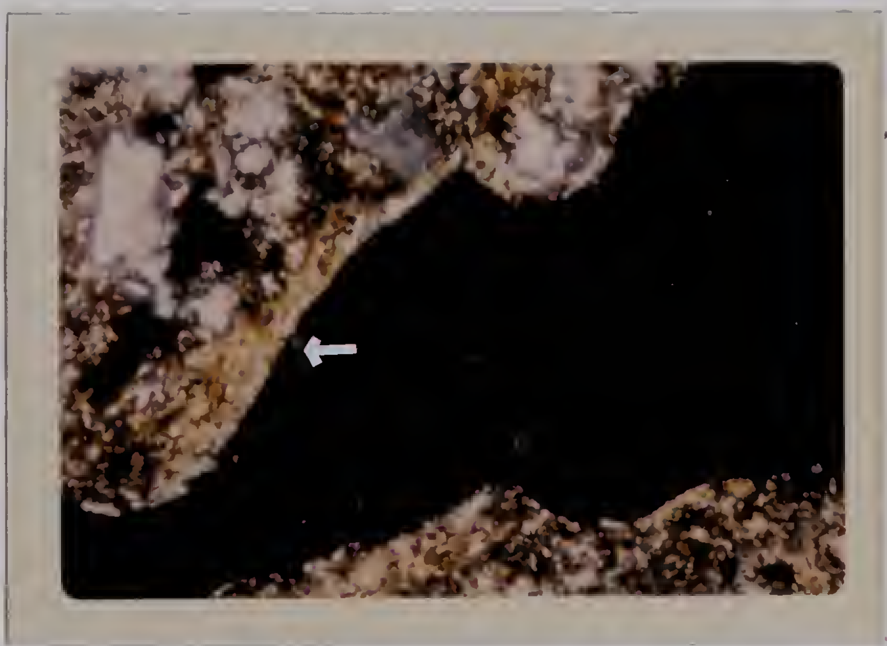


Figure 23

Diffuse, discontinuous cutan associated with channel wall. Thin section under crossed nicols. These indistinct cutanic (arrow) features are most typical of IIB horizons in the study area. 80x.

(Figure 23), and required judgment as to the genesis of the cutan. Brewer's (1973) statement that interpretation and genetic classification should follow the morphological classification was applicable here. While description of the soil fabric was reasonably straight forward, interpretation of pedologic features required more subjective thinking.

The concept that argillans, as seen in this section, represent evidence of translocation of clay has been debated. One set of arguments stated that clay, even if translocated downward into a horizon, would be negligible relative to total clay in most cases (Brewer 1978), and would not explain the decreases within the illuvial horizon, nor the increases in the illuvial horizon. Rather, weathering rates were more influential. That is, in situ production of clay would be greater than any removals that might have occurred in a horizon, or vice versa in the case of eluvial horizons. (Stephen 1960, Parvenova et al 1964, Oertel 1968, Valentine and Millette 1969). Another set of arguments was presented that stated the absence of argillans did not mean that illuviation was not taking place. Nettleton et al (1969) and Holzhey et al (1974) found that argillans were not preserved if the skrink-swell capacity was high or COLE >5%. Fedoroff (1974) stated that with time, all illuvial materials are incorporated into the matrix and therefore we see only those yet to be incorporated.

In the soils from the Sunwapta study area this illuvial material is often weakly separated from the matrix, irregular in thickness, and discontinuous in its distribution. Also the characteristics of patchy occurrence and the common papules and clay lamellae, has been termed typical for disrupted fabrics (Mermut and Pape 1971), or, may be a result of inheritance from parent material (pedorelic or lithorelics)

(Brewer 1976). The rounded shape of these papules suggested some transport had taken palce.

The estimated illuvial clay was relatively low when compared to representatives of the Luvisolic order from across Canada (McKeague et al 1972). Values as high as 8% are reported for Gray Brown Luvisols of southern Ontario. However, more recently (McKeague et al 1978) in a study of field designated Bt horizons, it was revealed that nearly half of those examined failed to contain the required 1% apparent illuvial clay as estimated from thin section.

In summary, the following observations were made:-

1. Only one out of the three IIB horizons contained greater than 1% apparent illuvial clay.

2. In the L1 pedon, the parent material (IICk horizon) contained more illuvial clay than the overlying IIB horizon. This was not observed in L3 pedon.

3. Where illuvial clay was encountered, it was often poorly separated from the matrix, or, existed as discrete papules or clay lamellae distributed in an irregular, patchy fashion.

4. Illuvial clay was present well into the IICK2 horizons.

5. Brownish plasma was seen in horizons presently undergoing, or recently completed, carbonate removal. It was not present in horizons that were unweathered or, that appeared to have had $CaCO_3$ equivalents reduced to 0% for sometime.

Based on these observations, it was apparent that the presence of illuvial clay was limited in these horizons, and was less than that required by definition of a Bt horizon (Canada Soil Survey Committee 1978a). The minor component of expanding phylosilicate minerals, and the absence of smectite from the clay fractions would exclude the possibility that perhaps argillans had formed but were not preserved.

The nature and distribution of this clay, along with the landscape positions of these sites, lead one to suspect possible inheritance through colluviation. This is especially true in the case of the L1 pedon. The processes of illuviation and carbonate removal are concurrent as indicated by pedological features within IICk horizons. It was assumed that the often observed brownish plasma was formed as residum resulting from carbonate dissolution, although there were no analytical data to support this statement.

Scanning electron microscopy. Scans at relatively low powers of magnification (less than 1000x) were taken of the surfaces of peds taken from the IIB horizons of the luvisolic-like soils in a manner similar to that of Lynn and Grossman (1970). The samples were air dried. A freeze drying preparation might have been more effective (Gillott 1974, Smart 1974) in avoiding surface tension damage, although the low proportion of expanding clays deemed this as not necessary.

In thin section the irregular distribution of well oriented argillans was noted. Likewise with S.E.M. this same trait was observed on ped exteriors. The surface characteristics were highly variable. Figure 24 shows a view of a ped from the IIB horizon from the L1 pedon. Note the relatively smooth surface over most of the field of view, but the lack of any orientation or coatings of fine material in the top right hand corner of the micrograph. Figure 25 shows the smooth portion of that surface but at higher magnification. Note the predominance of fine silt sized materials. A similar feature is shown in Figure 26. A coating of oriented fines over the silt and sand sized particles existed. In these cases, no differentiation was made between cutans formed from translocated clay (argillans) and those formed as a result of stress

(slickensides) processes. The extremely rough surfaces may have been points of contact between peds that were separated during sample preparation.

Excellent orientation of clay sized material is evident about the pore (about 100μm diameter) in Figure 27. Fine pores such as this were described as common to abundant in these horizons in the initial profile descriptions.

The fused and somewhat rounded aggregate shown in in Figure 28 was from the IIB1 horizon from the L3 pedon. This feature can be related well to the granoidic fabric described in thin section. The mass appeared to be an aggregation of various sized materials and exhibited an overall rounded (faunal origin?) morphology. Figure 29 displays another feature, interpreted in thin section, as cutanic plasma, this time seen from a different view. It appeared as if material, either precipitated from solution or deposited from suspension, had coated the adjacent void walls and come together at the one point.

Some areas such as that shown in Figure 27 show excellent orientation of surface particles. Other areas, for whatever reason, appear devoid of oriented material. No major differences in this respect were noted between horizons. Scans of the upper IICk, horizon from L1 pedon revealed a more flocculated nature of the clay sized platelets but orientation as described above was also noted in some areas. Innes (1971) was able to show well oriented, almost amorphous surfaces even at high mangificant ($>$7,000x). With these samples much of the coatings seemed to be fine silt size particles. While this feature may have resulted from air drying the samples before observing them, it would seem that the coatings were composed of generally coarser material than that

Figure 24

Scanning electron micrograph showing variable surface morphology of a ped extracted from the IIB horizon, (L1 pedon). 100x.

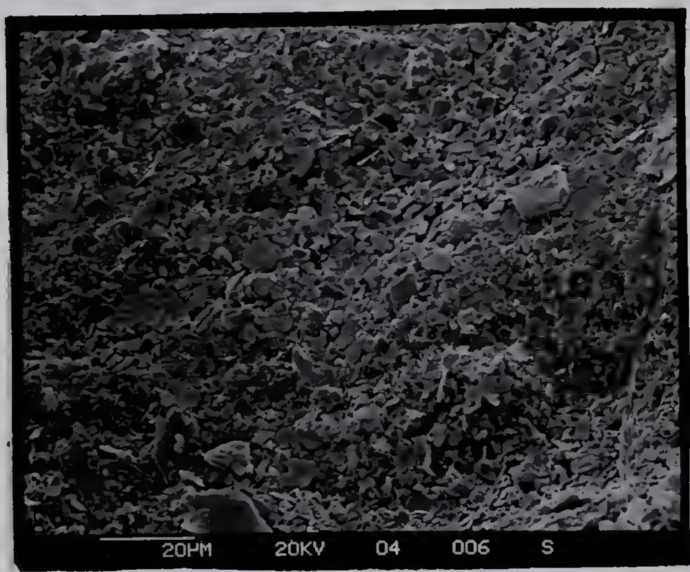


Figure 25

Scanning electron micrograph showing smooth portion from Figure 23, note the abundance of fine silt sized materials. 500x.

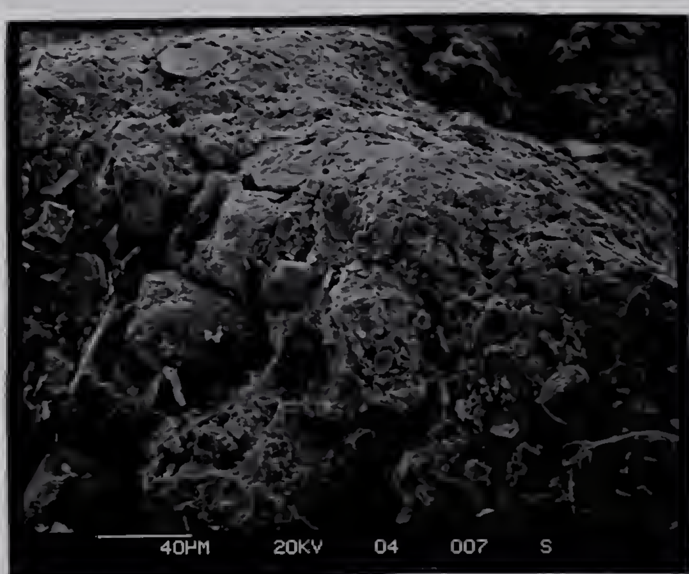


Figure 26

Scanning electron micrograph exhibiting well oriented fine material coating large sand sized particles. Approx. 250x.

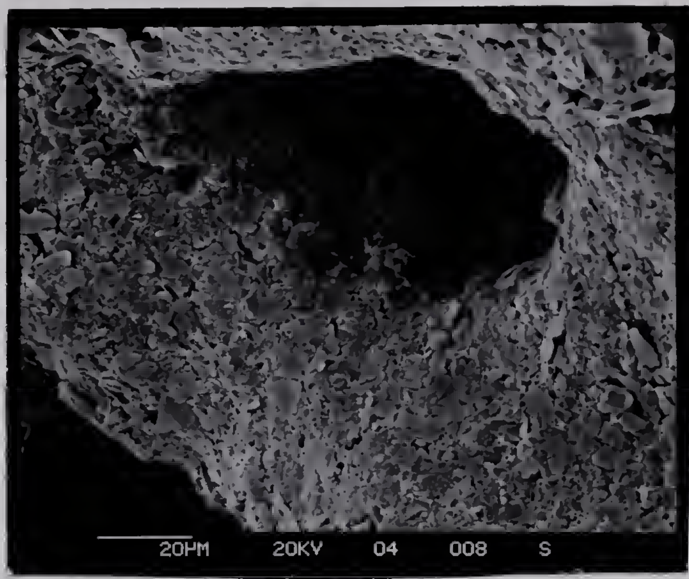


Figure 27

Scanning electron micrograph of a fine pore. Note the well oriented silt and clay about the ped surface. 500x.

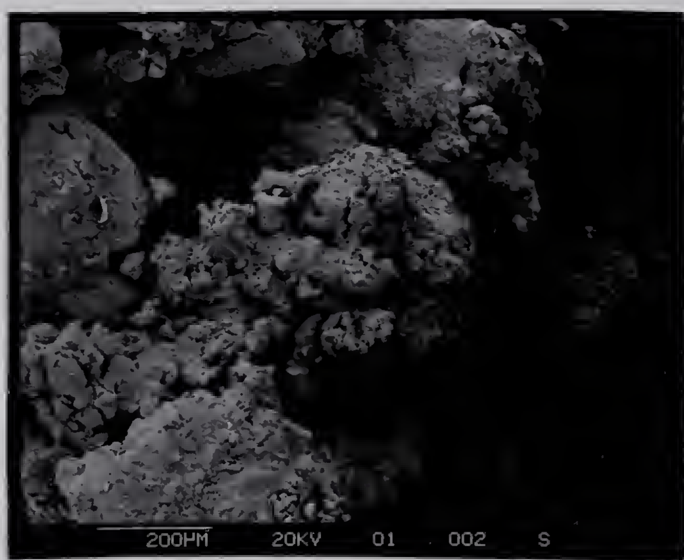


Figure 28

Low magnification scanning electron micrograph of an aggregated feature on ped surface. 50x.

Figure 29

Scanning electron micrograph of cutanic material, coating the void walls. Note the lack of oriented materials on the surface in the upper portion of the micrograph. Approx. 200x.

normally associated with classic argillans. The often diffuse nature and lack of continuous extinction of cutanic features as seen in thin section may perhaps be related to this coarser particle size.

Scanning electron microscopy revealed thin but locally well oriented clay and fine silt sized particles existing on ped surfaces. There was little difference between samples. Evidence, supporting the observations of discontinuous cutanic features seen in thin section, was gained.

Clay Mineralogy. In order to evaluate the nature of the clay minerals in the IIB horizons, a detailed study of the clay mineralogy through the entire profile of the selected soils is presented in this section.

It was concluded in Chapter 2 that the surface eolian parent material was composed of a mixture of volcanic ash plus local detritus. One of the observations which lead to this conclusion was the presence of a complex clay mineral suite existing within this material. Klages (1978) working in Montana, found the clay sized fraction of recent ashes to be entirely amorphous. The assumption was made therefore that the phylosilicates, detected using X.R.D., were inherited through contamination of the ash by local detritus (Dudas et al 1975b). If this assumption was correct, then these clay minerals must have initially been similar, if not identical, to those making up the present assemblage in the IICk horizons. A mineral is generally considered stable in the environment in which it was formed, and less stable in another environment (Coen and Arnold 1972). The clay mineral transformations seen in the upper parent material were in response to this change in environment. We see dramatic transformations that have occurred over a very

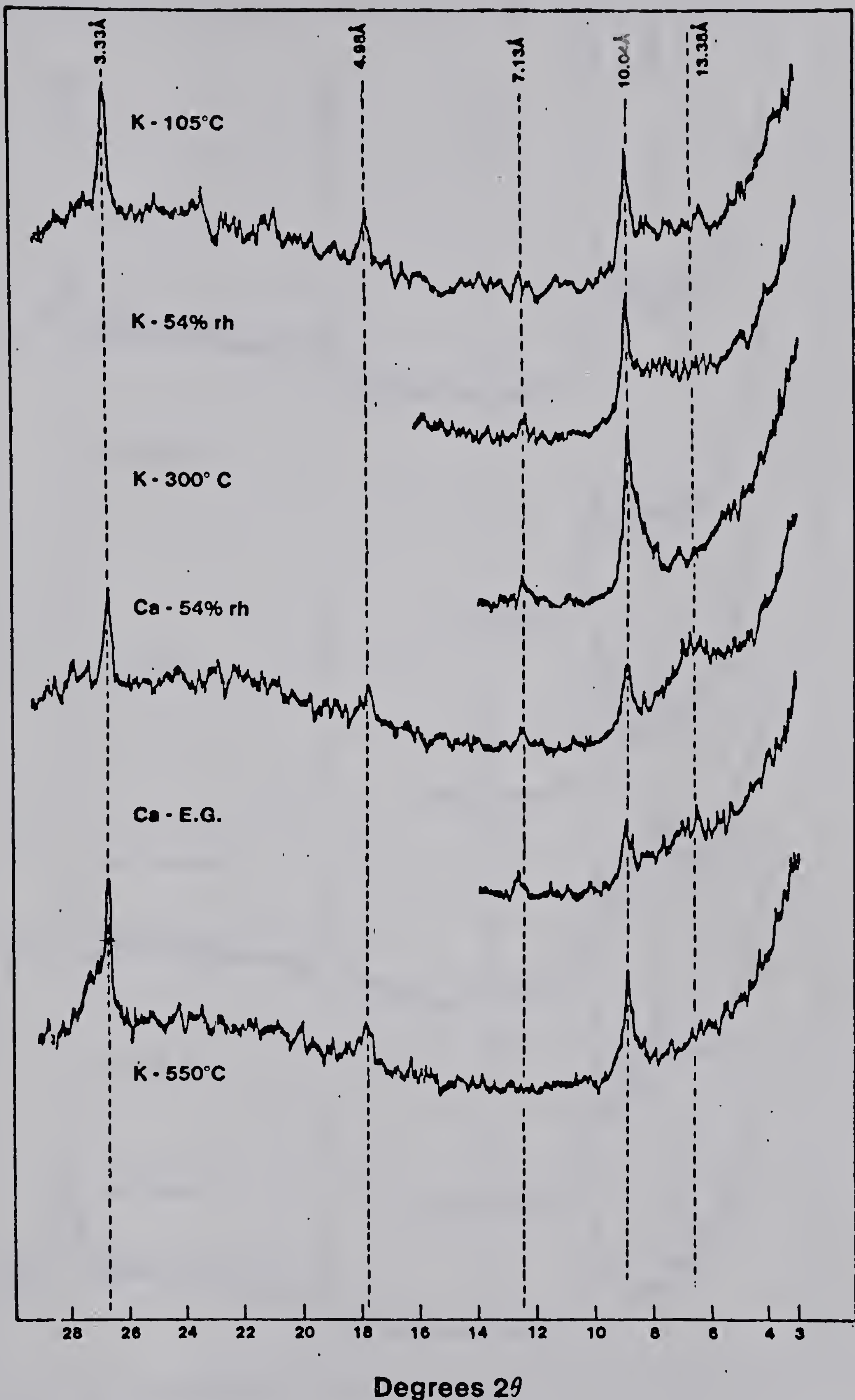


Figure 30

X-ray diffractogram of the coarse clay (2.0 - 0.2 μm) from the Ae horizon, L1 pedon.

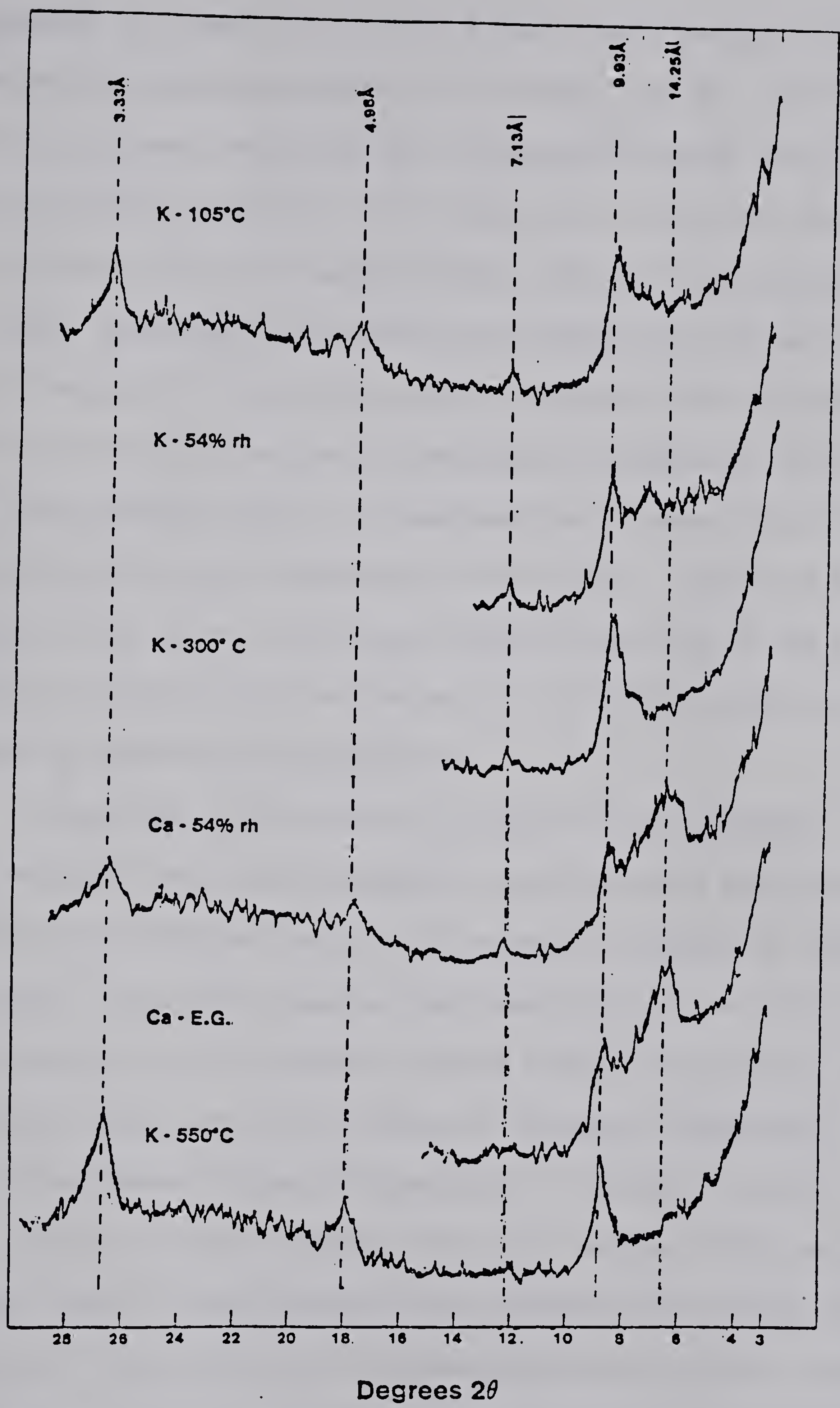


Figure 31

X-ray diffractogram of the fine clay (2.0 - 0.2 μm) from the Ae horizon, L1 pedon.

short geologic time span, not only as a result of a change from the environment in which these minerals were formed, but as a result of a change in environment caused by their incorporation with highly weatherable, acidic material. It is this latter event which caused them to be distinctly different, qualitatively, from the clay minerals found in the lower, exceedingly calcareous parent material as briefly described in Chapter 2. It was felt that perhaps this striking qualititative difference could be used to advantage in attempting to ascertain, based on clay mineral suites, if translocation of material from the upper solum into the IIB horizons was taking place. Secondly, the clay mineralogy of the Podzolic soils was compared with that of the luvisol-like soils, to determine if the presence of the IIB horizons was in any way linked to mineralogical properties.

It was stated that Figure 4 (Chapter 2) represented a suite of clay minerals dominated by muscovite, chlorite and a minor component of kaolinite as evidenced from the HCl selective dissolution treatment (Brown 1961). Therefore, assuming that these minerals were the dominant phylosilicates originally present within the surficial parent material, one could look at the effects of pedogenic weathering. The results of the investigation are summarized in Tables 12 to 14.

Figures 30 and 31 display the X.R.D. patterns obtained from an Ae horizon. The two diffractograms were similar with slightly higher proportion of vermiculite and correspondingly less chloritic intergrade material present in the coarse fraction. The chlorite has disappeared, a common occurrence in acidic Ae horizons. This was discussed by Brydon et al (1968) and was considered typical in podzolic sola. They felt that the decomposition product was an amorphous aluminosilicate. Rai

and Lindsay (1975) showed chlorite to be thermodynamically unstable in acid evnironments but quite stable in alkaline ones. Kodama and Schnitzer (1973) showed the dissolution of chlorite minerals by fulvic acid. This organic acid would be present within the Ae of these soils. Jackson (1963) discussed the degradation of chlorite and hypothesized the production of an intergrade mineral. Wilson (1970) felt that chlorite and any intergrades that it might form may be present in the B horizon but not the A. Chlorite has been experimentally transformed to vermiculite in the lab (Ross and Kodoma 1974). This involves a number of steps including heating to achieve dehyroxylation followed by acid extractions of interlayer (brucite sheet) materials. The dehyroxylation characteristics of chlorite have been used to characterize its presence within a mixed assemblage (Alexiades and Jackson 1967). The conditions for the removal of the interlayer sheet, without destruction of the remaining crystal lattice are seldom met in the soil environment.

The domination of the clay fraction by a chloritic intergrade mineral in these Ae horizions is the most striking feature observed in the diffractograms. The production of intergrades, vermiculite, and often smectite, had been considered a possible procedure by which to measure the degree of podzolization (Brydon et al 1968). Guven and Kerr (1968) felt that vermiculite was a precursor to montmorillinite. There was no indication of this final step having taken place in the soils at Sunwapta. Pettapiece and Pawluk (1972) and King and Brewster (1976) found smectite in the soils they studied in the Canadian Rocky Mountains as did Cortes and Franzmeir (1972) in volcanic ash at high elevation in the Andes Mountains in Columbia. The conditions normally assumed necessary for its formation has been outlined (Jackson 1963, Brydon et al 1968, Dudas et al 1975a). A final characteristic to note is the readily

collapsible nature of these Al-hydroxy interlayered minerals. In both the fine and coarse samples the plateau evident from 10 Å to 14 Å in the K-sat. 105°C and K-sat. 54% R.H. treatments disappeared upon heating to 300°C and further heating to 550°C created narrowing at the base of the 10 Å peak indicated complete collapse. This indicated the interlayer position was not completely filled nor was polymerization of the hydroxy material well developed.

Figure 32 represents a typical set of diffractograms for a Bf horizon. A situation existed where a number of factors were contributing to the amorphous materials within these horizons (Chapter 2). Hence difficulty in obtaining interpretable patterns was encountered. The domination of amorphous material in Podzolic B horizons was well noted (Brydon et al 1968, Pawluk 1963, Brydon and Shimoda 1972, Coen 1970), even in soils without volcanic ash. In this study the situation was such that no interpretable pattern was obtained for either clay fraction. Subsequent oxalate treatment enabled interpretation of coarse clays but not fine clay. While the patterns were similar to those from the Ae horizon one major difference did exist. Rather than a plateau extending from 10 Å to 14 Å, a sharp peak at just over 12 Å was evident. The peak was resistant to collapse upon the 300°C heat treatment and even the 550°C treatment caused only a shift to 11 Å. The Ca-saturated clays exhibited almost no 10 Å peak, and K_2O contents were very low indicating little unaltered mica remained within the suite. Depotasafication was more advanced here than in any other horizon, and interlaying with well polymerized Al-hydroxy material was more complete. There was some indication of discrete chlorite present, but as with the Ae horizon, smectite was entirely absent.

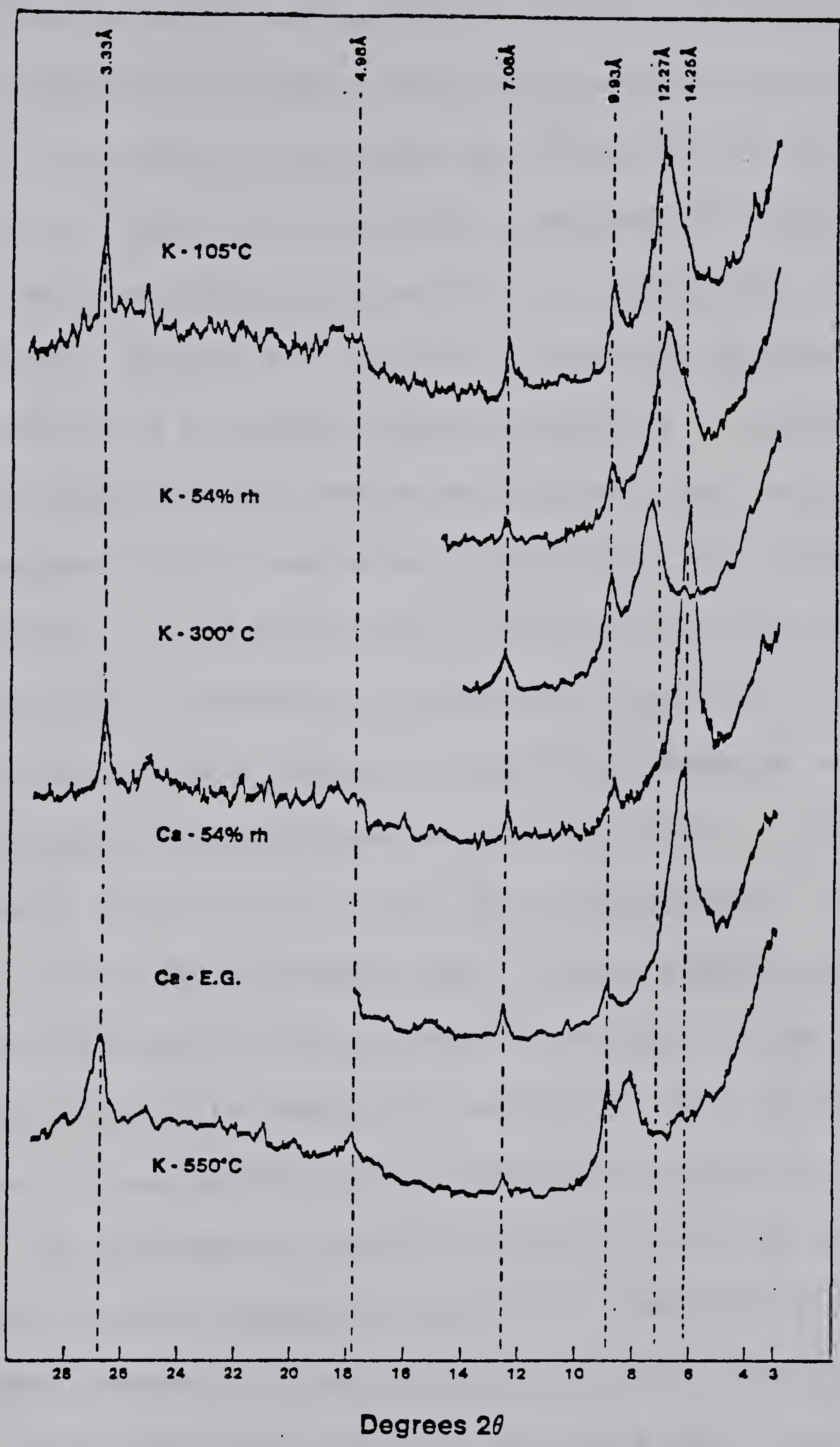


Figure 32

X-ray diffractogram of the coarse clay from the Bf horizon, L3 pedon.

The formation of the well developed chloritic intergrade minerals was considered to initially involve the weathering of mica (van Ryswk 1969). An essential first step was thought to be the penetration of protons (H^+ ions) into the lattice, neutralizing sites of negative charge and thus allowing the hydration and removal of fixed K ions (Kukovsky 1969). As well as K depletion, there may have been minor amounts of lattice Si and Al cations removed, resulting in a crystal lattice having some statistically unoccupied octahedral and tetrahedral sites, and subsequent largely unsatisfied interlayer cation positions (Guven and Kerr 1966). These were readily filled by hydrated cations or charged hydroxy species. Oxidation of lattice Fe^{+2} resulted in reduction of layer charge (Jackson 1965, Nagasawa et al 1974). Numerous studies in the Canadian Rockies have described the "chloritization of vermiculite", considered the next step in this weathering sequence. (Beke and Pawluk 1971, Pettapiece and Pawluk 1972, King and Brewster 1976). These B horizons had Al and Fe hydroxy material produced either through the weathering of ash _in situ_ (Pettapiece and Pawluk 1972), or through the accumulation of translocated material from above (Brydon et al 1968). As well, in environments with pH less than 5.0, Al may come from within the mineral lattice (Vincente et al 1977). They felt that intergrades formed most frequently through interaction with aliphatic and phenolic acids, these being more important than the mineral acids in these soil clay reactions. Jackson (1965) described the formation of intergrade minerals as a form of mild desilication, achieved through the accumulation of sesquoxidic materials on surfaces of layer silicates, and ultimately resulting in the formation of pedogenic chlorite. Veith (1978) determined that vermiculite absorbed the more acidic forms of

Al-hydroxy material $Al(OH)^{+(1-1.5)}$ and $Al(OH)^{+2}$, and that the clay mineral reacted as a weak acid in acting as a proton acceptor. In this way, the vermiculite, initially formed through depotasafication and structural alteration of mica, acted as a reservoir, or sink, for Al compounds liberated through weathering regardless of source (Pawluk and Brewer 1975b). Jackson (1963) described this interlaying process as an "anti-gibbsite" effect.

Figures 33 through 38 represent the X.R.D. patterns obtained from clays extracted from IIB horizons. The base lines are lower and the discrete, well formed peaks are characteristic of clays from the glacial till parent material. Very little weathering of the coarse clay fraction was seen, in fact, it appeared little altered from that fraction in the IICk2 horizon. In the fine clay fraction, the 14 Å chlorite peak was observed through most of the treatments and the presence of vermiculite, and some intergrade material was evident. The Ca-saturated clay solvated with ethylene glycol exhibited some tendency towards expansion past 14 Å. Vincente et al (1977) found an intergrade formed between vermiculite and true smectite. That is, no rehydration after heating, yet fixation of two layers of ethylene glycol with a resulting 16.3 Å peak. We may have seen this same behaviour with the "soil vermiculite" present in the IIB horizons. The extensive interlaying of these minerals within the upper solum prevented this same behaviour being observed even though some discrete vermiculite was present.

The same horizon in the L3 pedon showed a much more intense weathering pattern. The intercalation of vermiculite was evident in Figure 36. The mineral however was not resistant to collapse as seen in the 300°C treatment. The Ca-saturated clays showed high background

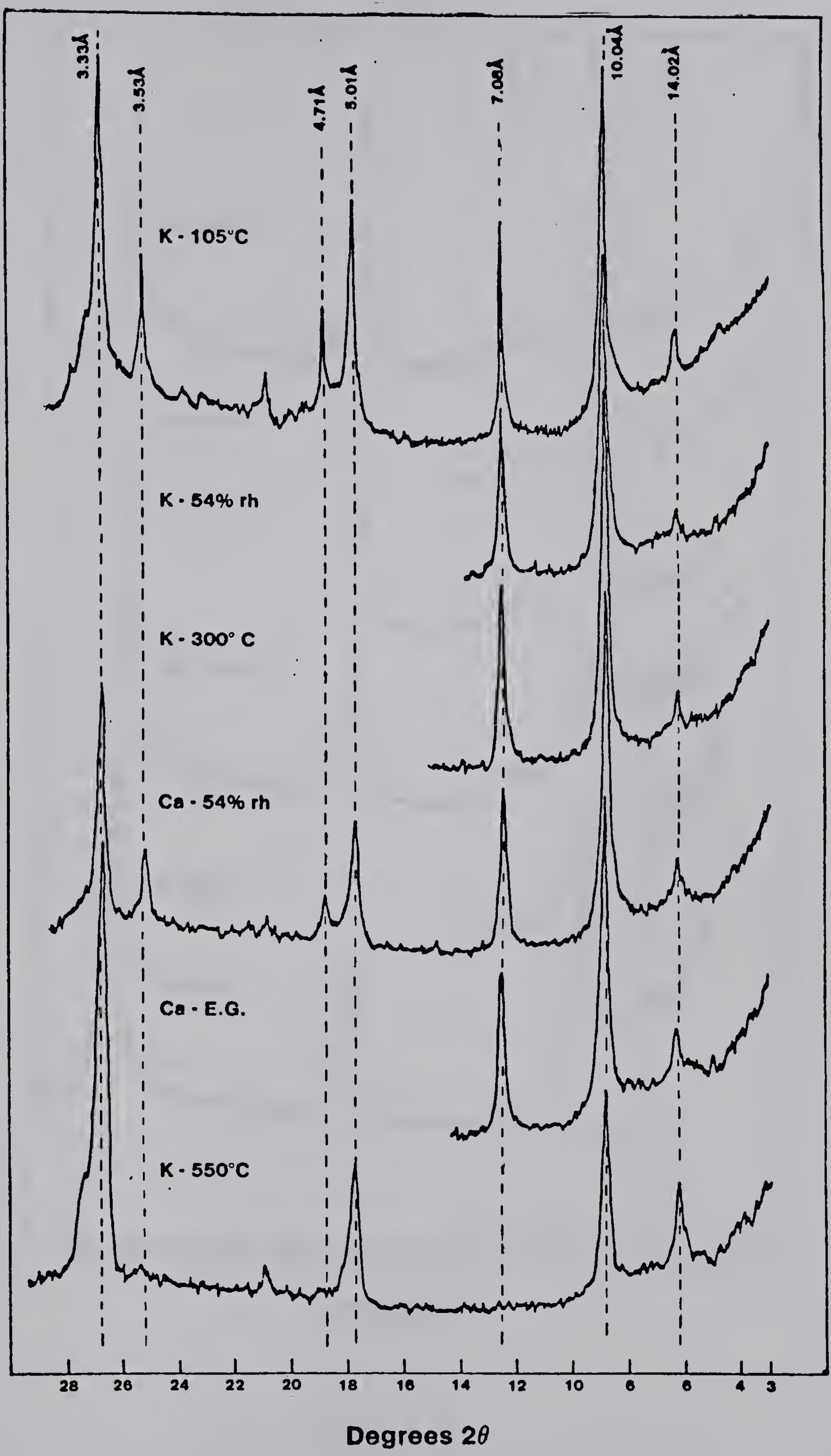


Figure 33

X-ray diffractogram of the coarse clay from the IIB horizon, L1 pedon.

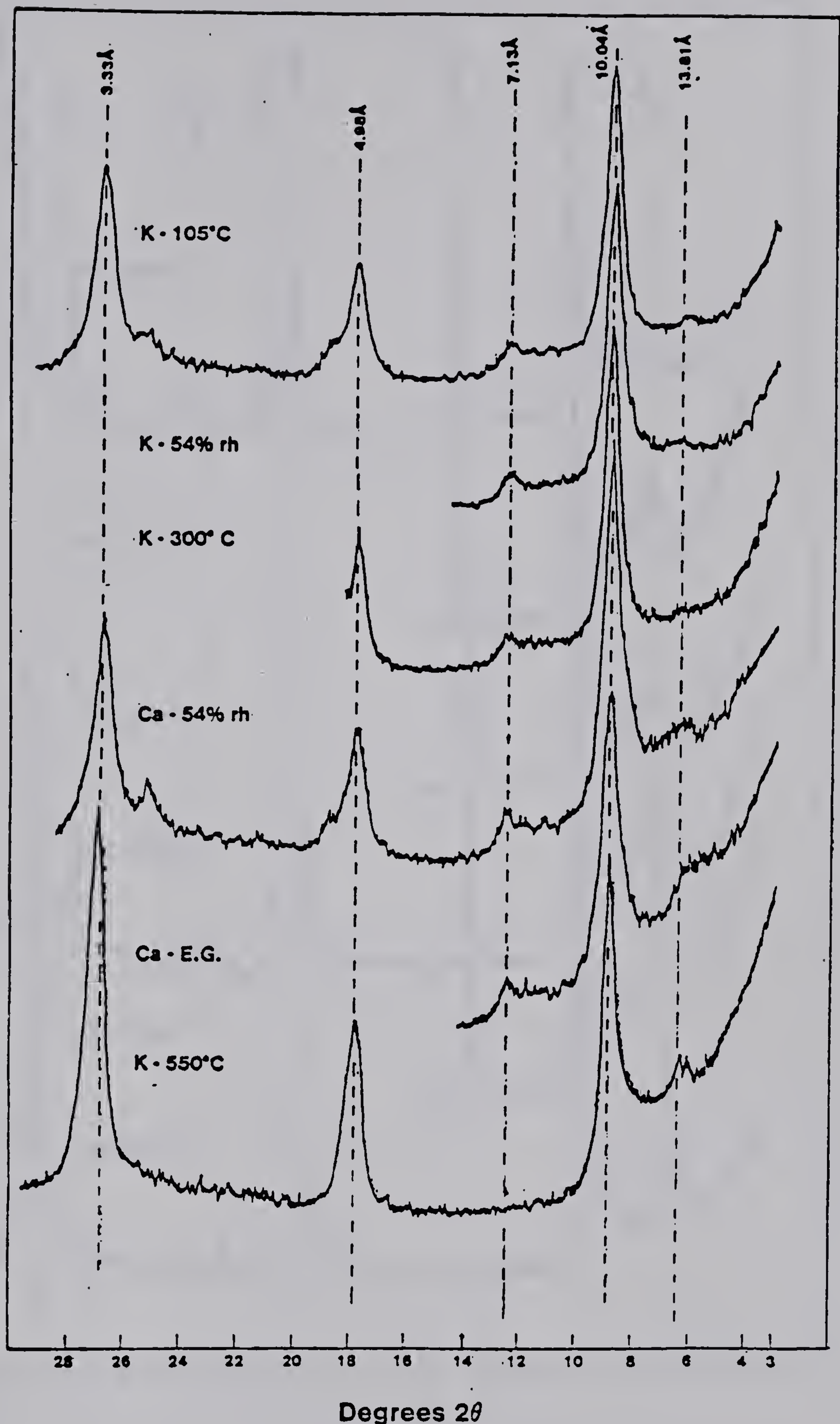


Figure 34

X-ray diffractogram of the fine clay from the IIB horizon, L1 pedon.

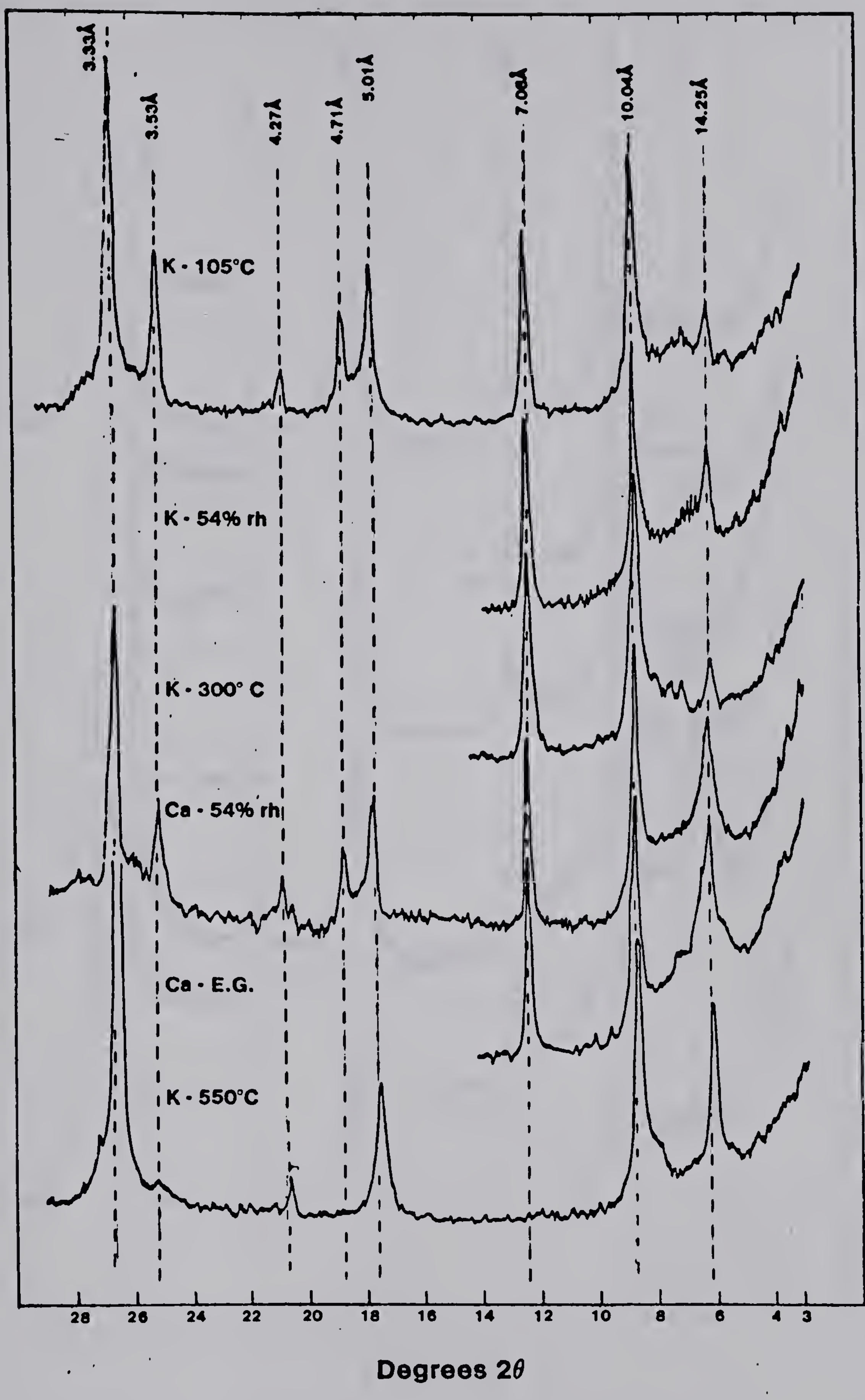


Figure 35

X-ray diffractogram of the coarse clay from the IIB1 horizon, L3 pedon.

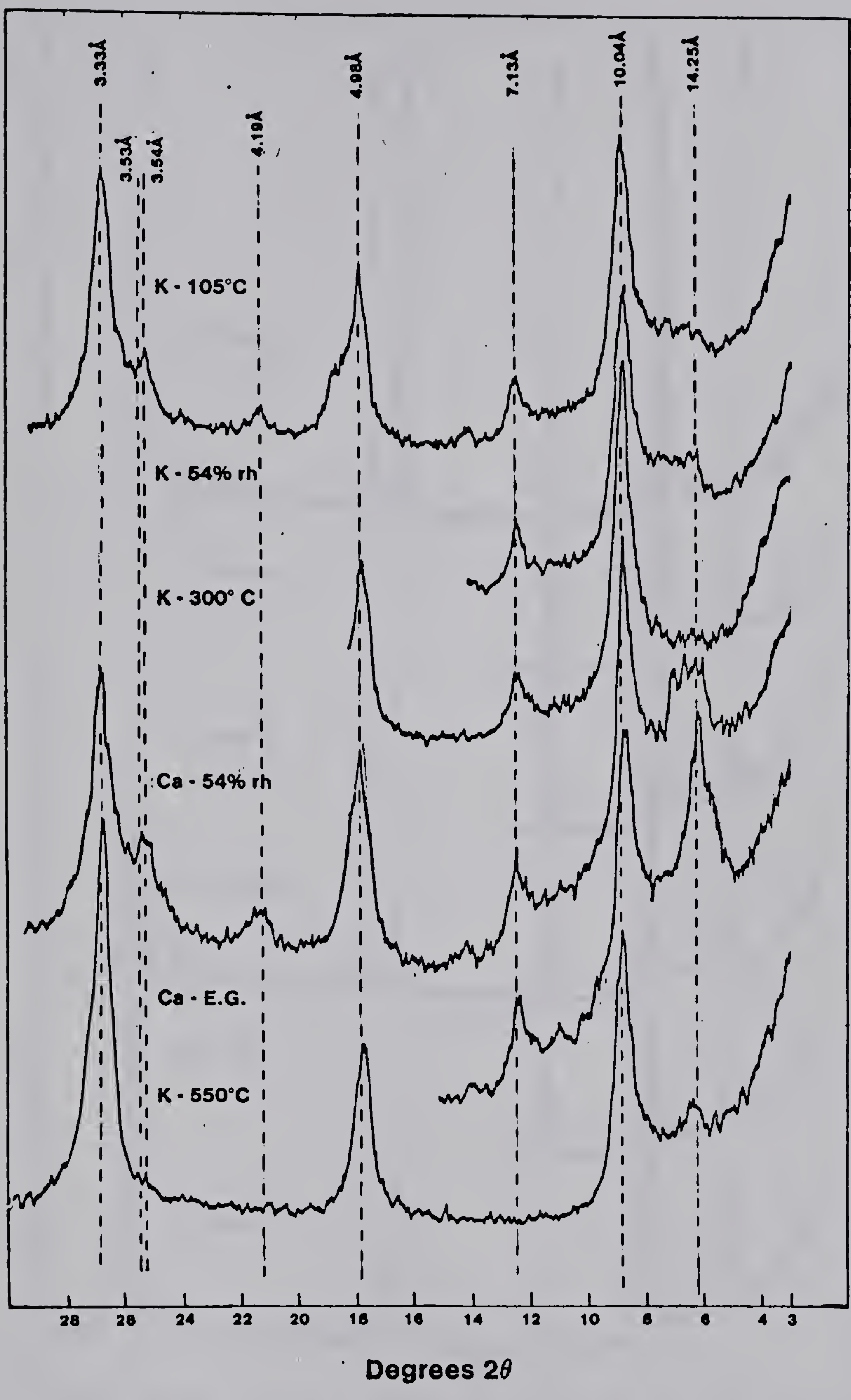


Figure 36

X-ray diffractogram of the fine clay from the IIB1 horizon, L3 pedon.

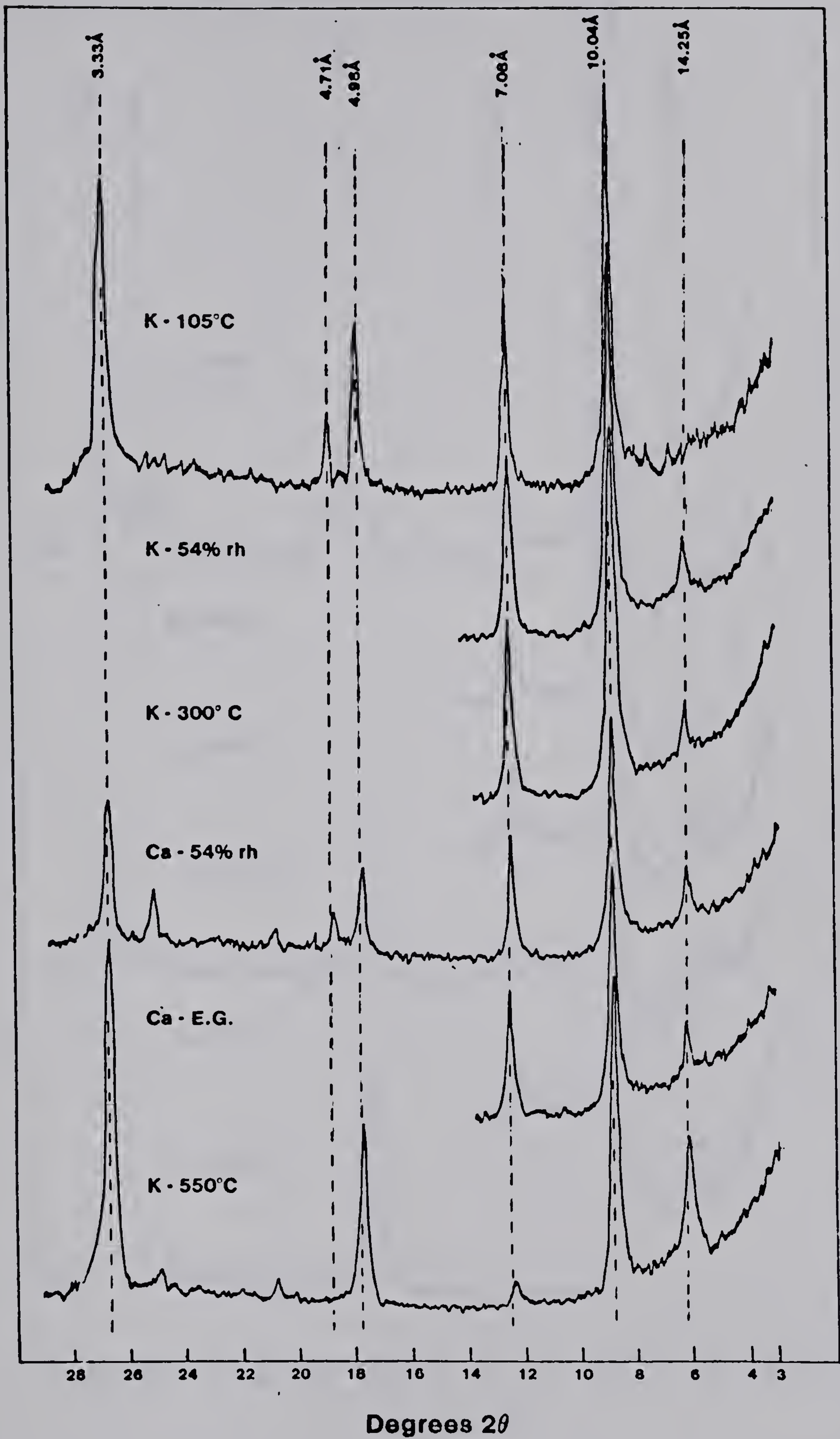


Figure 37

X-ray diffractogram of the coarse clay from the IIB2 horizon, L3 pedon.

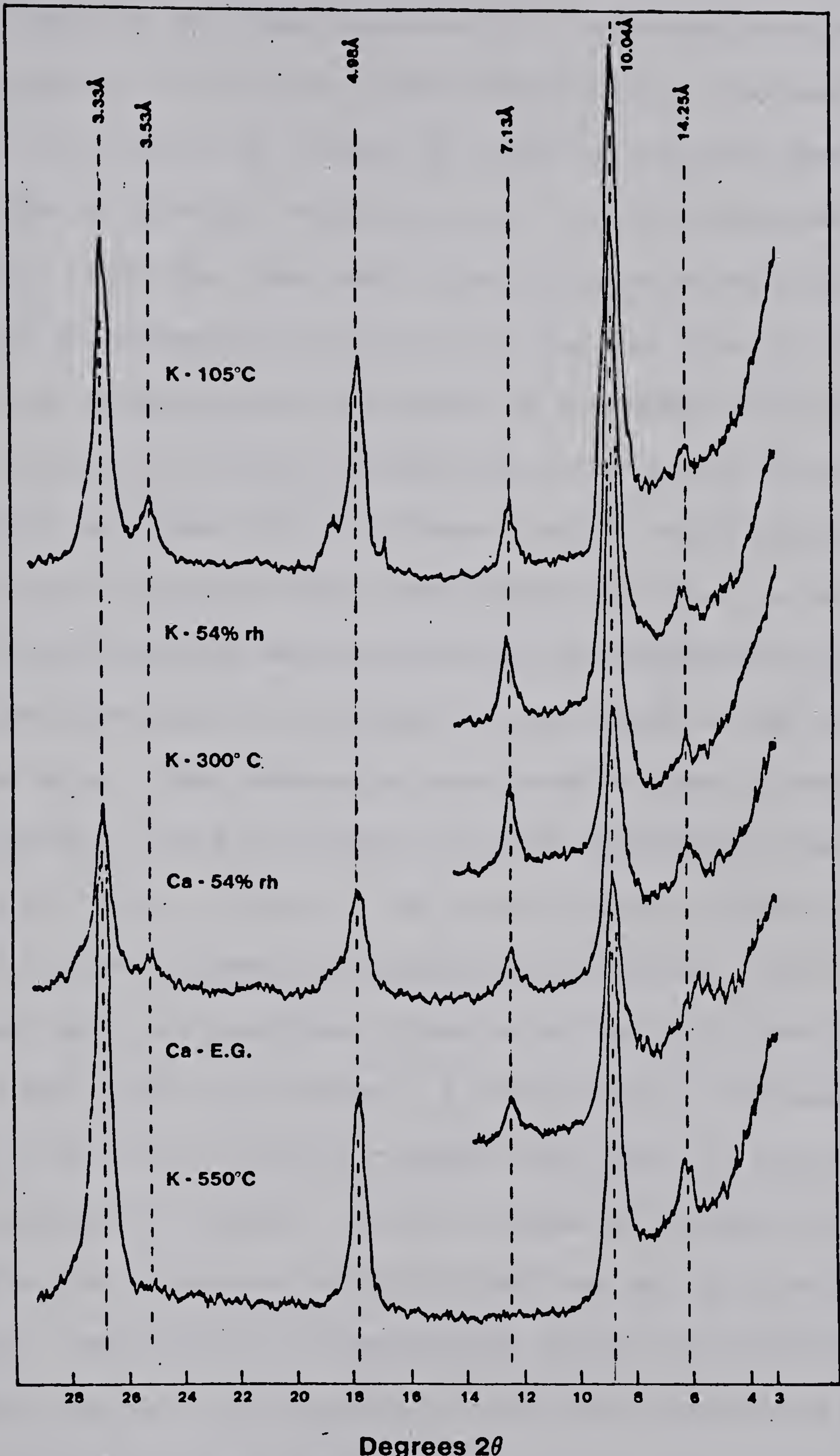


Figure 38

X-ray diffractogram of the fine clay from the IIB2 horizon, L3 pedon.

between 10 Å and 13 Å and strong peaks at 14 Å. K-saturation caused most of this to revert to 10 Å and was interpreted as a major component of vermiculite. The coarse clay (Figure 35) exhibited much less dramatic weathering effects although a shoulder at 10.5 - 11.0 Å persisted with heat treatments indicating some stable interlaying had taken place. Whether or not the degradation of chlorite in the fine clays in these IIB horizons was involved in the production of this intergrade was unclear. De Connick et al (1975), working with a very similar mineral suite claimed to have been able to differentiate the origin of alteration products using selective (HCl) dissolution techniques. A swelling mineral was thought to have resulted from chlorite degradation, while a chloritic intergrade mineral was deduced to have formed through the alteration of mica. These conclusions were based on these alteration products reaction to the HCl treatment. No such investigation was attempted in this study. Figure 37 and 38 show patterns derived for the IIB2 horizon from the L3 pedon to be only mildly weathered. The coarse clay was essentially unaltered mica, chlorite and kaolinite, the fine clays showed some vermiculite present. A strong tendency for expansion past 14 Å with the ethylene glycol treatment was related to the presence of a "soil vermiculite" mineral. The pH is closer to neutral (6.1) in this horizon, and so the alterations associated with the acid environments were not seen. The production of vermiculite through the weathering of mica is common, and has been reported by other workers within the upper subalpine (Bockheim 1972, van Ryswk 1969).

The clays from the IICk horizon of the L1 pedon are almost identical to those seen in the IIB2 horizon from L3 pedon. The coarse clay is made up of predominantly muscovite and chlorite. It should be

pointed out that while biotite may be present in the soil, it is not identified within the clay fraction. Its highly weatherable nature causes it to not persist as fine sized grains in the soil environment. The dioctahedral species, muscovite, is more resistant and persists in the clay fraction. Carroll (1974) considers detrital muscovite to be almost exclusively the 2M polytype.

Comparison of the total clays ($< 2\ \mu m$) from the Podzolic soils with clay fractions discussed in the two luvisolic-like pedons revealed no major differences between the two (Tables 12 - 14). They followed the same weathering pattern, and only differed in the absence of a IIB horizon. There appears to be more amorphous material present in the Ae horizon of the P2 pedon than in any other. The usual pattern of lowest K_2O values in the Bf horizon also varied. It would seem that perhaps mixing had occurred here although sand mineralogy did not indicate this.

In summary, the following observations were made:-

1. The hydroxy interlayered mineral was most strongly developed in the Bf horizons. These horizons also contain the highest content of amorphous material and lowest K_2O values in the profiles.

2. The clays from the IIB1 horizon from the L3 pedon were more altered than those from the same horizon in L1 pedon.

3. There was no evidence of any regularly interstratified mineral present in any horizon.

4. There was no evidence of any smectite formation in any of the horizons studied.

The surface area values were generally low (a result of only very limited expanding minerals) and somewhat erratic. The CEC values were greatest in the Bf horizon. This was due largely to the

Table 12

Results of analysis of clay fractions, Pedon L1.

Horizon	Sample No.	Mica	Hydrous Mica	Chlorite	Chloritic Intergrade	Vermiculite	Kaolinite	Amphorous Material	Chemical Analysis			**
									% K_2O	Surface area m^2/gm	CEC me/100 gm	% Clay
Ae	2f*	2	1		3	2		2	2.6	328	nd	1
	2c	2	1		3	2		2	2.3	165	31.1	4
Bf	3f(o)							3	nd	nd	nd	2
	3c(o)	2			3	2		2	1.1	198	100.8	8
IIB2	4f	3	1	1	1	2	1		4.1	367	29.5	4
	4c	3	1	2		1	1		4.6	110	17.9	23
IICk1	5f	3	1	2		2	1		5.5	375	26.5	8
	5c	3		2		1	1		4.6	100	12.9	27
IICk2	6f	3	tr	2		tr	1		5.0	380	29.1	3
	6c	3		3			1		4.9	111	11.5	7

3. Dominant - > 35%
2. Major 10 - 35%
1. Minor - < 10%
tr Trace
nd Not determined

* f = fine clay fraction (< 0.2 μm)
c = coarse clay fraction (0.2 - 2.0 μm)
(o) = oxalate treated

** clay fraction expressed as % of fine earth fraction after carbonate removal.

Table 13

Results of analysis of clay fractions, Pedon L3.

Horizon	Sample No.	Mica	Hydrous Mica	Chlorite	Chloritic Intergrade	Vermiculite	Kaolinite	Amphorous Material	Chemical Analysis			% Clay
									% K_2O	Surface area m^2/gm	CEC me/100 gm	
Ae	14f	2	1		2	3		2	nd	nd	nd	2
	14c	2	1		2	2		2	2.3	155	30.4	5
Bf	15f(o)	1			2	2		3-2	nd	nd	nd	2
	15c(o)	1	1	1	3	2		3-2	1.4	192	70.3	8
IIB1	16f	2	1	1	1	3	1	1	3.0	344	33.0	4
	16c	2		2	2	2	1		3.5	153	18.5	19
IIB2	17f	3	1	2	tr	1	1	1	4.2	358	28.5	5
	17c	3	tr	3			1		4.3	156	19.3	23
IICk1	18f	3	1	1	tr	1	1	1	5.5	347	22.9	7
	18c	3		3			1		4.2	116	12.6	15
IICk2	19f	3	1	2	tr	1	1	1	nd	nd	nd	6
	19c	3		3				1	nd	nd	nd	15

Table 14

Results of Analysis of clay fraction, Pedon P2 and B3.*

Horizon	Sample No.	Mica	Hydrous Mica	Chlorite	Chloritic Intergrade	Vermiculite	Kaolinite	Amphorous Material	Chemical Analysis K_2O	Surface Area m^2/gm	CEC me/100 gm	% Clay
P2												
Ae	28 (o)	2	1		2	2		3	2.1	174	44.1	4
Bf	29 (o)	2		2	2	2	1	2	2.9	242	73.6	7
IIBc	30	3	1	2	tr	1	1		2.6	218	24.4	11
IICk	31	3		3			1		4.6	174	15.5	11
B3												
Ae	43	2	1	1	2	2	tr	2	2.2	216	46.1	8
Bf	44 (o)	2	1	2	3	2	1	2	1.8	182	39.5	19
IICk1	45	3	tr	3			1		3.4	173	23.0	35
IICk2	46	3		3			1		4.6	139	10.2	31

* all analysis performed on total clay (i.e. $< 2 \mu m$).

amorphous material, including organic matter, present. Researchers have found that in horizons containing amorphous aluminosilicates, much of the CEC was pH dependant (Chichester et al 1969). This is also true where Al-hydroxy material occupied interlayer positions of 2:1 expanding minerals. Perrott (1977) described, in detail, the surface charge characteristics of these non-cyrstaline materials.

Based on the observations there was no clear evidence, to establish whether or not, clay minerals had translocated downward through the profile. It was observed that the intergrade mineral in the Bf horizons was relatively resistant to collapse with heat treatment. On the other hand, the intergrade mineral found in the IIB horizons was readily collapsed even with 300^{o}C treatment. It seemed likely that this mineral had formed in place within the IIB horizon, and was not present as a result of illuviation from above. However, the possibility existed that much of the Al-hydroxy material found in the interlayer position had migrated downward in solution from the upper solum. It appeared that this process of intercalation was operative in only the more acid environments (pH $<$5.5), while in more neutral ones, weathering proceeded only as far as the vermiculite stage.

Conclusions

It was concluded that, while some clay illuviation had taken place, these horizons did not meet the criteria of the Canadian Bt horizon (Canadian Soil Survey Committee 1978a), nor did these soils fit the concept of the Gray Luvisol great group.

The multiple working hypothesis stated at the beginning of this Chapter and restated below, was evaluated according to the foregoing evidence. The IIB horizons, which showed striking increases in clay

relative to the horizons above and below, and strong to moderate subangular blocky structure, resulted from:

1. The pedogenic dissolution of highly calcareous parent material. That is, structural rearrangement and changes in the relative proportion of particle sizes due to the removal of carbonate material.

2. Classic lessivage processes with the formation of a true pedogenic argillic (Bt) horizon.

3. Non contemporary soil forming proccesses, i.e. the horizons were paleo features formed under different environment conditions than exist today.

Evidence was obtained to support hypothesis 1. It was concluded that large changes in soil texture resulted from the removal of carbonates from the glacial till parent material. Structural features were undoubtedly produced as a result of the loss of considerable soil mass. It was shown that fabrics became less dense as weathering progressed. A relationship between the development of a subangular blocky structure and carbonate removal was evident in all luvisolic-like soils.

Conclusive evidence to support hypothesis 2 was not obtained. It was felt that if lessivage processes had been operative within these soils, then continuous well developed argillans would have been viewed in thin section. While illuvial clay was observed in all IIB horizons, the nature and distribution of this material indicated that contemporary lessivage was an inconsequential process within these soils. Likewise S.E.M. revealed ped exteriors to lack continuous coatings of clay sized material. Fine silt sized particles were often observed coating the surfaces of these peds. If the illuvial clay, seen as lamallae and papules, was not the result of present processes then proccesses such as those stated in hypothesis 3 would be supported. The

illuvial clay might therefore have been derived under more favourable conditions for lessivage at some time in the past, been subjected to disruption, and then as a result, seen in this study as essentially inherited features. It was concluded that the abundance of papular features in IICkl horizons may have originated in this manner. There is no way however to positively identify any of these characteristics as truly being paleo features.

A similar hypothesis could be used to explain the presence or absence of the IIB horizons from within the solum of soils of the Sunwapta study area. Landscape positions which underwent more severe geomorphic disturbances would not possess disruptive fabric features, but would lack a weathered till (IIB) horizon altogether. Where this had occurred (i.e. truncation) the luvisolic-like morphologies would be absent and the more conventional Podzolic morphology (Ae, Bf, IICkl, IICk2 sequence) would result.

Chapter 4

DISTRIBUTION AND ORIGIN OF IRON AND ALUMINIUM COMPOUNDS WITHIN SELECTED PROFILES

Introduction

The study of iron and aluminium was valuable as a tool to further understanding the pedogenic processes operating within the soil system. High elevation soils with mixed parent materials (usually including volcanic ash) have received considerable attention in this regard over the last decade. Presumably the rather bright red colours of the B horizons formed within the upper solum of these soils have triggered this interest. Numerous workers, including van Ryswyk (1969), Beke and Pawluk (1971), Bockheim (1972), Singer and Ugolini (1974), Pawluk and Brewer (1975b) and King and Brewster (1976) have used chemical extraction methods to partition the inferred forms of Fe and Al, and, to aid in classifying these soils (McKeague 1966, McKeague and Day 1966, McKeague 1967).

Blume and Schwertmann (1969) described some of the evaluations that were possible, not only with extractable Fe and Al values but other mobile metals including Mn. MacKeague et al (1971), outlined the various forms of these elements affected by each of the extractions, and Lutwick and Dormaar (1973) applied this to a study of numerous Podzolic and Brunisolic soils from western Canada.

These extractions were conducted on the fine earth fraction ($<$ 2 mm). A pyrophosphate extraction (Bascomb 1968, Kononova and Belchikova 1970, Wada and Higashi 1976) was conducted to estimate the

the amount of organically complexed Fe and Al. The acid ammonium oxalate treatment was used to extract all amorphous forms of Fe (McKeague and Day 1968, Schwertmann 1973) and to a lesser extent Al from each of the samples. A final extraction with Na-dithionite was used to obtain an estimate of the total "free" iron and aluminium present in each sample (Mehra and Jackson 1960). Considerable debate has arisen over the exact chemical nature and origin of materials extracted by each procedure, especially when dealing with pyroclastic deposits. Research into this problem (Dudas and Harward 1971, Pawluk 1972, Arshad et al 1972) has indicated that while many of these values are undoubtedly empirical, standard procedures produce consistent results. Some of the procedures, especially those involving the use of ammonium oxalate, were shown to be less specific than ideally hypothesized.

These extractions were performed on all the horizons of the soils choosen for detailed study in order to observe the forms and distribution of iron and aluminium throughout the profile. As well, pyrophospate extractions were run on all B horizons in order to help classify the soils of the study area (Appendix 1). Elemental analysis of lithic fragments within weathered and unweathered materials was carried out to help appraise the origin of these extractable materials.

Materials and Methods

Individual samples were prepared for each extraction by grinding fine earth samples to pass a 60 mesh sieve. Na-dithonite-citrate-bicarbonate (Mehra and Jackson 1960), acid ammonium oxalate (McKeague and Day 1966), and Na-pyrophosphate extractable Fe and Al were determined by atomic absorption spectroscopy (Raad et al 1969) following

the procedures outlined by the Canada Soil Survey Committee (1978b). Extractions were run on duplicate samples and means were reported. Total elemental concentrations of lithic fragments (gravels and cobbles) were obtained by grinding samples to a fine powder and subsequently treating them with HCl - HF acids to achieve dissolution as described by Pawluk (1967). Analysis for Al, Fe, Mg, Ca, Na and K was undertaken also using atomic absorption spectroscopy.

Organic C was determined by wet oxidation employing the Walkley Black method and following the procedure outlined in Canada Soil Survey Committee (1978b).

Results and Discussion

Results of chemical extractions. The results of the three chemical extractions are presented in Table 15. Figures for both Fe and Al are given as well as certain ratios used to aid interpretation and classification. These values are comparable to those reported by other workers for similar parent materials and elevation.

Pyrophosphate values were extremely low in the Ae horizons, but increased to a maximum in the underlying Bf horizons in all profiles. Values in the till parent material were lower and decreased with depth. Fe and Al values paralleled each other, apparently indicating that chelation with organic acids was affecting both elements in a similar manner. Their accumulation in the B horizons was typical for materials undergoing podzolization processes.

Oxalate values were high and generally followed the same pattern. There were however some notable exceptions. While Al values were consistently highest in the Bf horizons, maximum Fe values appeared

Table 15

Extractable Fe and Al values for selected soil profiles.

Pedon	Horizon	Sample	Pyrophospate Fe_p	Al_p	Oxalate Fe_o	Al_o	Dithionite Fe_d	Al_d	$\frac{Fe_o}{Fe_d}$	$\frac{Fe_p+Al_p}{Fe_d+Al_d}$
			%		%		%			
L1	Ae	2	0.03	0.04	0.08	0.06	0.08	0.11	1.11	0.39
	Bf	3	0.74	0.98	0.96	1.76	1.22	1.30	0.78	0.68
	IIBm	4	0.18	0.08	0.44	0.14	1.71	0.31	0.25	0.13
	IICk1	5	0.01	0.00	0.29	0.03	1.05	0.19	0.27	-
	IICk2	6	0.01	0.00	0.22	0.02	0.52	0.08	0.42	-
L3	Ae	14	0.06	0.12	0.08	0.08	0.08	0.12	1.00	0.90
	Bf	15	0.72	0.99	1.17	1.33	1.17	1.06	1.00	0.76
	IIBm1	16	0.29	0.13	0.94	0.31	2.27	0.33	0.41	0.16
	IIBm2	17	0.21	0.07	1.19	0.15	3.04	0.30	0.39	0.08
	IICk1	18	0.07	0.02	0.58	0.04	1.52	0.21	0.38	-
	IICk2	19	0.06	0.01	0.52	0.03	0.74	0.15	0.70	-
P2	Ae	28	0.11	0.12	0.15	0.12	0.14	0.13	1.07	0.85
	Bf	29	0.38	0.49	1.50	2.65	2.10	1.12	0.71	0.27
	IIBC	30	0.24	0.14	1.75	0.79	2.02	1.05	0.87	0.11
	IICk	31	0.12	0.03	0.58	0.07	0.66	0.08	0.87	-
B3	Ae	43	0.14	0.12	0.14	0.11	0.15	0.09	0.93	1.08
	Bf	44	0.50	0.41	1.81	1.39	1.89	0.78	0.95	0.33
	IICk1	45	0.20	0.05	0.95	0.11	0.98	0.16	0.96	-
	IICk2	46	0.02	0.00	0.34	0.03	0.39	0.10	0.87	-

in the upper portion of the till material in two of the four pedons studied. The Al values were generally quite low. Within the IICk2 horizons, Fe values tended to be higher by as much as a full order of magnitude.

While the pyrophosphate and oxalate procedures were designed to extract predominantly amorphous forms of Fe and Al from the soil, the third extraction using Na-dithionite removed crystalline oxides of iron and aluminium as well. Hence values were generally highest for this extraction. The tendency for highest Fe values to have originated from till horizons was seen once again. A value of over 3% extractable iron was obtained from the IIB2 horizon from pedon L3 and represented the highest value generated in this study. A similar value was reported as a maximum figure in studies elsewhere (Bockheim 1972, Pawluk and Brewer 1975). However, Singer and Ugolini (1974) working in Washington state with horizons formed of relatively pure volcanic ash, determined dithionite Fe values as no higher than 2%. Dithonite Al values (as did all Al values), reached a maximum in the Bf horizons and not in the upper till. Difficulties existed in interpreting these figures (Table 15) as absolute results as mentioned in the introduction to this chapter. Anomalous results of oxalate Al, and in one case, pyrophospate Fe (Singer and Ugolini 1974) seem to be due mainly to the relative effectiveness of each extractant in solubilizing the amorphous aluminosilicate present within the ashy parent materials.

There were essentially no Fe oxides in the Ae horizon, and organically complexed Fe was very low. In the Bf horizons the activity ratios, (Blume and Schwertmann 1969) remained very high, but most of the Fe was in organic form. We saw an entirely different situation in the

IIB horizons. The activity ratios and pyrophosphate values were low, but dithionite values were high. It appeared that the weathering of the till material had resulted in large increases in the Fe oxide content, although it was noted that dithionite Fe values were significant even in the IICk2 horizons. It did not appear as though movement of iron into the till from the surface material was occurring. If the large increase in iron was due to its translocation and subsequent enrichment in the IIB horizons, one would have presumably expected to see similar increases in Al values (particularly pyrophosphate). It was therefore concluded that the free iron must have been produced in situ and that translocation of Fe and Al between the two parent materials was limited. However, Singer et al (1978) showed that Si moved readily through the entire solum of soils formed on similar parent materials, and Si would likely have done the same here.

Micromorphological aspects of Fe weathering. During the course of micromorphological investigations particular attention was paid to the features observed that might help clarify the weathering processes involved with Fe in this two phase soil system. Iron oxides were observed existing primarily as irregular, diffuse nodules, or where less concentrated, simply ferrugenous zones within the soil matrix. In all cases, these were associated with till materials. Furthermore, specific investigation showed there to be excellent correlation with features seen in thin section, and the results of chemical extractions. Where oxalate and dithionite Fe values were high, so was the occurrence of nodules and ferrugenous zones.

There were two types of features seen that related to Fe weathering. Figure 39 shows a large lithic fragment (non calcareous)

weathering out in situ in the IIB horizon of the L1 pedon. Note the ferrugenous material produced as a result, and the existence of the diffuse nodules in the upper left hand corner and bottom center. An excellent example of the second feature is shown in Figure 40. It illustrates well rounded granoidic fabric found within glacial till material incorporated into the Bf of the L3 profile. Two well developed nodules were seen which were not associated with any discrete lithic fragments weathering in the immediate area. It should be mentioned that these interpretations were made without elemental data and were based solely on the morphological and optical characteristics.

Concentrations of ferrugenous materials were not observed within the silty eolian parent material. Instead the overall fabric exhibited a strong reddish colour but discrete nodules were absent. However, individual mineral grains were often coated, as observed in the petrographic analysis of the fine sand separate. Within the till material, the matrix was largely unaffected by iron staining (other than discrete nodules). The IIB horizons were generally light coloured (10YR 6/4 - 4/4d) even though their Fe oxide contents were higher than those in the overlying Bf horizons.

Nodules were described in each of the IIB horizons studied (see Appendix 2) and their abundance followed well, the Fe values derived from the extraction procedures. Also, the petrographic examination of the fine sands showed there to be large relative increases in the number of opaque mineral grains present within the heavy minerals (sp. grav. $>$ 2.92) of the till horizons. Assuming that these were predominantly iron oxides, then further support was added to the conclusion that iron, within the IIB horizons, was largely

Figure 39

Ferrugeous material produced through the weathering of lithic fragments _in situ_ (arrow). Thin section under crossed nicols. 20x.

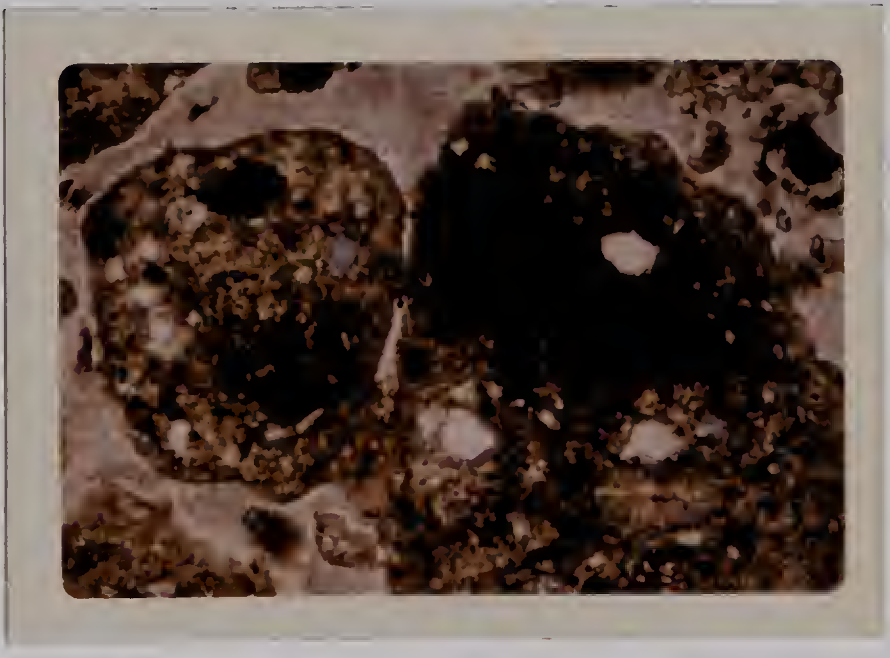


Figure 40

Iron oxide nodules formed within a matrigranoidic fabric. Thin section under partially crossed nicols. Note the irregular, diffuse nature of these pedological features. 20x.

inherited rather than accumulated through translocation from the overlying parent material.

Elemental analysis of lithic fragments. Elemental analysis was conducted on numerous lithic fragments found within the parent materials of the soils of Sunwapta Pass. It was concluded that considerable free Fe (and to a lesser extent Al) was being added to the soil system through the in situ weathering of both calcareous and non-calcareous lithic fragments (i.e. non ash sources). Tables 16 and 17 present the results of these analysis. Table 16 attempts to show the effects of weathering on the proportions of various elements within such a calcareous fragment. Sample 1 represents the elemental composition (expressed on an oxide basis) of the interior of the fragment, sample 2 the weathering rind about that fragment, while sample 3 represents the composition of material left behind as a residual "ghost". The fragment was originally derived from the glacial till but had been incorporated into the base of the silty surficial parent material where it had undergone severe acid weathering. Initially (sample 1), Ca and Mg were the dominant elements, but as weathering progressed (samples 2 and 3), these elements were released from the fragment, solubilized and ultimately removed from the solum. The resulting product was a material rich in Fe and Al, and largely depleted of the more soluble elements Ca, Mg, K, and Na. Although the absolute quantity of Fe and Al did not change, the relative proportions of these elements (and undoubtedly Si) was vastly increased. The very high organic C content (almost 10%) of sample 3 was considered very significant. It was concluded that organic acids (presumably fulvic acids) played a dominant role in the dissolution of the calcareous material and in the subsequent complexation,

Table 16

Effects of weathering on the distribution and proportions of various elements within a calcareous lithic fragment.

Sample Description	% by weight expressed as oxides						Organic C
	CaO	MgO	K_2O	Na_2O	Fe_2O_3	Al_2O_3	
1. Unweathered calcareous lithic fragment.	79.5	7.6	1.3	1.5	2.2	6.6	n.d.
2. Black residue scraped from surface of weathered fragment.	7.4	2.2	3.2	4.3	15.7	20.6	n.d.
3. Black residue, original lithic fragment not present.	12.0	4.0	1.9	0.8	10.5	36.6	9.6

Table 17

Elemental composition of various lithic fragments found within the soil parent materials.

Sample Description	% by weight expressed as oxides					
	CaO	MgO	K_2O	Na_2O	Fe_2O_3	Al_2O_3
1. non calcareous, grey, micaeous	0.8	3.5	4.2	1.5	3.5	28.3
2. non carcareous, partially weathered, red fragment	0.6	6.3	5.4	0.4	8.1	16.8
3. "Red" limestone	47.5	4.2	2.7	0.4	8.8	18.0
4. dark grey carbonate rock	28.0	5.3	4.5	0.3	8.6	24.0
5. limestone fragment	95.0	3.4	0.3	0.0	1.3	1.9
6. Mazama ash*	1.6	0.6	5.3	10.1	4.5	20.0
7. Bridge R. ash*	1.6	0.5	5.6	9.3	4.1	19.8

*From Smith and Westgate 1969, average elemental concentrations of glasses recalculated on oxide basis.

through chelation, of the remaining metallic elements.

Various fragments were analysed for their elemental composition and the results shown on Table 17. Samples 1 and 2 were removed from the Bf horizon in pedon B3. They were partially weathered and non calcareous, and showed high Fe and Al contents. Samples 3 and 4 represent samples removed from IICk1 horizons from various pedons. These calcareous fragments had undergone partial weathering as indicated by moderate CaO values, but showed surprisingly high Fe and Al values. This seemed to indicate that these fragments consisted of intimate mixtures of silicate minerals within a carbonaceous matrix, rather than any distinct, Fe rich, carbonate (anterite, siderite) minerals. Sample 5 was an unweathered calcareous fragment found at depth in the P2 pedon. It appeared to be a good example of calcitic limestone, although it was found not to be pure. Samples 6 and 7 represent figures recalculated from values reported by Smith and Westgate (1969) for glass shards isolated from the two volcanic ashes considered present in the study area. With all the samples, the remaining proportion of elements would be predominantly SiO_2. It was evident that the glass shards were no higher in Fe and Al than many of the local lithic materials. The presence of podzolic horizons has often been attributed to volcanic ash and its highly weatherable nature. However, it was clear that "highly weatherable" calcareous materials, equally rich in these elements, were also present and had made significant contributions to the soil system. Keeping in mind the initial average value of 60% $CaCO_3$ equivalent in the till horizons, it was obvious that increases in Fe and Al through negative enrichment as weathering proceeded, could become considerable. Furthermore as it was demonstrated that the surficial eolian parent

material was composed of both local detritus and volcanic ash; iron in the Bf horizons could have originated as much from local materials as from ash sources.

Conclusions

Fe and Al orginated in its various forms from both ash and non ash sources. The podzolic B horizon in the upper solum of these profiles showed strong accumulation of organically complexed Fe and Al, while the IIB horizons within the till material, showed large contents of oxides produced primarily through weathering *in situ*. There appeared to be little interaction between the two materials in terms of translocated Fe and Al. Good correlation between features seen in thin section and those indicated through chemical analysis was evident.

The extraction results were also used as a basis for classification of these soils. All of the upper B horizons (except from the B2 pedon), meet all chemical criteria for a Canadian Podzolic (Bf) horizon (Canada Soil Survey Committee 1978a). The Bf horizons from the L2 and L3 pedons were 10 cm thick. It was felt that these soils exemplified Podzols in all other respects and so were left classified as such. However these horizons did not meet all the criteria outlined for spodic horizons (Soil Survey Staff 1975) as defined in the U.S. classification system. Both systems use a total pyrophosphate extractable (Fe and Al) to clay ratio as criterian, but set different limits. It was the limit of this ratio having to be >0.2, which eliminated most of these samples as Spodosols (Appendix 1). The criteria designed for classifying Spodosols formed on pyroclastic materials (ratio of pyrophospate to dithionite extractions) was only met by the Bf horizon from the L1 and L3 pedons (Table 15).

Chapter 5

SUMMARY

It was concluded that the soils studied within the upper subalpine bioclimatic subzone at Sunwapta Pass had formed within two distinct parent geologic materials of different origin and mineralogical composition. Dramatic differences between the two were demonstrated in terms of sand and clay mineralogy, particle size distribution, and micromorphology.

Based primarily on particle size distribution curves, it was concluded that the silty surficial parent material was eolian in origin. The sand mineralogy revealed a mixed assemblage composed of locally derived detritus and volcanic ash. It was concluded that any stratification of the ash and/or local detritus that may have existed had not been preserved. Although the volcanic ash had most likely originated from more than one source, the deposit was concluded to be essentially mineralogically uniform. Certain quantitative differences were seen in the heavy mineral suites of horizons formed within this eolian parent material. However, a distinct lithologic discontinuity between Ae and Bf horizons could not be established based solely on petrographic observations. The clay minerals appeared highly weathered, and differences in their make up between horizons was attributed to pedogenic weathering processes rather than inherited properties. Banded and isobanded microstructures predominated while plasmic fabrics tended to be silaesepic with localized isotic regions often present. Incorporation of organic matter into the upper horizons by soil

fauna was common, especially within Bf horizons.

The glacial till parent material was demonstrated to be dominated by carbonate minerals. The clay mineralogy was relatively simple; assemblages were composed of muscovite, chlorite, and minor amounts of kaolinite. Where the till had weathered, vermiculite formation through the degradation of mica became significant. Microfabrics were generally dense, and the tendency towards the development of horizontally aligned structural units, prevalent within the eolian material, was absent. Porphyric and granoidic-porphyric fabrics were predominant. A variety of plasmic fabrics was observed and usually described as vo-mosepic to vo-skel-masepic in IIB horizons and upper zones of IICkl horizons. Faunal activity appeared to be limited to rare isolated aggrotubules.

It was concluded that lessivage was not a particularly strong contemporary pedogenic process within these soils. There was evidence (clay papules, lamellae, plugs, in-filled voids) to suggest that illuviation of clay had taken place at sometime in the past, perhaps when environmental conditions were less severe than at present (altithermal period). Apparent textural B horizons found within the upper portion of the till were concluded to have developed their anomalous morphology through the differential removal of carbonate material from the soil mass. Resultant changes in the particle size distribution, and the reorganization of structural units were the dominant processes involved in producing the relative clay increases and strong pedality. They were formed entirely within till parent material and did not span the parent material discontinuity as had been reported elsewhere (Hutcheson and Bailey 1955, Asomoa and Protz 1972) on similar landforms (i.e. eolian veneers over moraine). The presence or absence of IIB

horizons was concluded to have been controlled by past erosional and/or depositional events, rather than any mineralogical properties.

There was no evidence of any authigenic clay mineral formation, rather transformations involving detrital minerals were evident. The weathering of mica to vermiculte and the subsequent interlaying of this mineral (i.e. "chloritization") represented the major clay weathering sequence.

The B horizons formed in the eolian parent material meet all the criteria set for Podzolic B horizons, but lacked the micromorphological features normally associated with them. They did not meet all the requirements of a spodic horizon as outlined in the U.S. taxonomic system (Soil Survey Staff 1975). Highest concentrations of organically complexed Fe and Al were encountered in the surficial parent material, while highest concentrations of Fe oxides and hydroxides were found to be in the B horizons formed within the upper portion of the glacial till. The origin of these Fe compounds in the IIB horizons was concluded to be primarily the <u>in situ</u> weathering of a variety of lithic sources. The lack of well distributed illuvial clay resulted in their being classified as Bm horizons. Thus, the majority of the soils fell into the Orthic Humo-Ferric Podzol subgroup. The soil from the B2 pedon was classified as an Eluviated Dystric Brunisol due to the lack of pyrophosphate extractable Fe and Al in the upper B horizon. The soil at the B1 site was considered a Cumulic Regosol.

Based solely on the information gathered from profiles examined in this study, no clear cut post-glacial stratigraphy could be described due to the rather thorough mixing of materials which had taken place over the years. However, correlation of pedogenic features with

Holocene events was possible utilizing information derived through studies of deposits elsewhere in the Canadian Rockies. Similar types of correlations have been done in the past (Pettapiece 1970, King and Brewster 1976). Briefly the following sequence of events was envisaged (by this author and those previously mentioned) to have likely produced the soil morphologies observed in the Sunwapta Pass study site.

Approximately 8,500 - 9,000 years ago the ice had receeded into its present locale, and concurrent with this retreat, loess was distributed about the landsacpe. Initial pedogenesis reduced the carbonate content and lowered the pH of the surface loess and perhaps the upper portion of the underlying till as well. Approximately 2,000 years after deglaciation, Mazama ash was deposited in the study area. The dacitic ash was incorporated into the surface material through pedoturbation processes. Due to low clay content this material lacked significant buffering capacity, and so very quickly a sharp drop in pH would have occurred. Low molecular weight organic acids produced as decomposition products of the upper subalpine vegetation litter and carbonic acid resulting from biological evolution of CO_2 all contributed to this drop. Loessial activity was likely to have been more or less continuous throughout the altithermal period. Luvisolic profiles may have developed at this time. When environmental conditions became moister, chemical weathering proceded more rapidly within the surficial eolian parent material. Mass wasting (perhaps linked with forest fires) could have occurred at any time at various locations on the landscape. In doing so, fresh unweathered till materials were exposed at some sites, or, in less severe cases the simple disruption of established features occurred. A second ash fall 2,400 years ago provided additional

material to the surficial deposit. Continued leaching and acidic chemical weathering, produced a podzolic horizon sequence within the uppermost parent material. Glacial till horizons (IIB) would either thicken, or begin to undergo carbonate removal (IIBC or IICk1) depending on the past stability of the site. In this way, the soil profiles as described in this study could have formed. There was not enough evidence preserved in the profiles to attempt a more detailed interpretation of the geomorphic histories of these sites.

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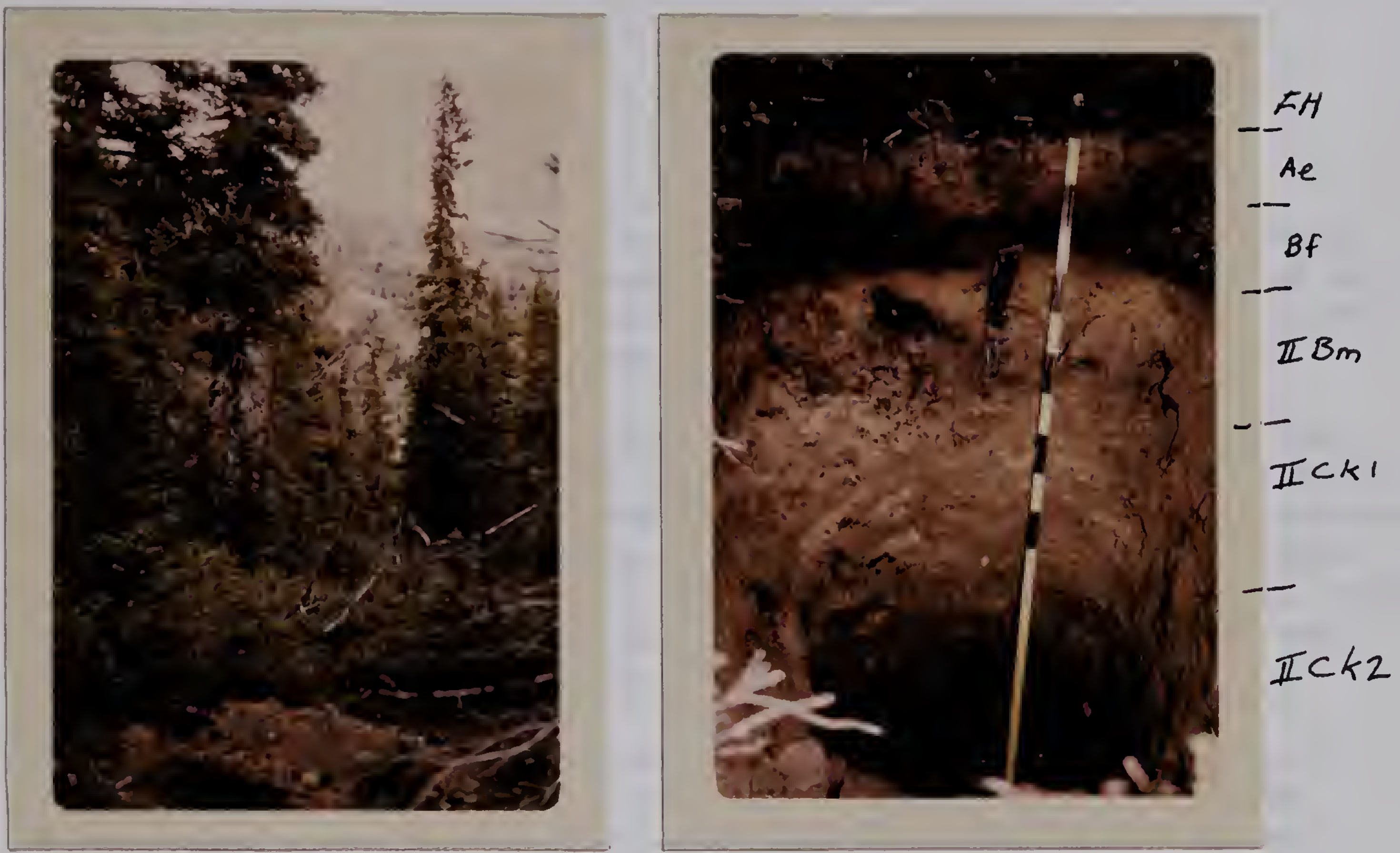
APPENDIX 1. Site descriptions and results of routine analysis.



Photographs of L1 site and profile.

<u>PEDON NO. L1</u> Date described: August 29, 1977.

Location:	100 m above Brewster's staff camp, off small road leading to water tank.
Military Grid Co-ordinates:	11 U MH 852 847.
Landform classification:	Eolian veneer/inclined moraine.
Parent Material:	Fine loamy and fine silty, mixed volcanic ash and local detritus/coarse loamy, extremely calcareous mixed sedimentary.
Site form:	Regular.
Seepage:	Some evidence of intermitent lateral seepage.
Drainage:	Well drained.
Solum thickness:	35 cms.
Elevation:	2,050 m asl.
Slope:	3%, complex.
Sample site position:	middle-lower slope.
Aspect:	Northeast
Classification:	Orthic Humo-Ferric Podzol.

Sample No.	Horizon	Depth (cms)	
1	F-H	6-0	Brownish black (7.5YR 2/2d); semi-decomposed and well decomposed fibrous organic materials; abundant roots of all sizes, abrupt, smooth boundary; 5-8 cms thick; pH 4.5.
2	Ae	0-6	Light brownish gray (7.5YR 7/1 d) and grayish brown (7.5.YR 5/2 m); silt loam; weak, medium subangular blocky to moderate, fine platy; loose plentiful, very fine to medium roots, a few coarse roots; common, very fine and fine pores; abrupt, wavy boundary; 5-9 cms thick; pH 4.6.
3	Bf	6-17	Brown (7.5YR 5/4 d) and dark reddish brown (5YR 3/2 m); silt; loam; weak, medium subangular block to weak fine platy; very friable, loose; plentiful roots of all sizes; common, very fine pores; abrupt, wavy boundary; 8-15 cms thick; pH 5.0.
4	IIBm	17-35	Very pale brown (10YR 7/4 d), and yellowish brown (10YR 5/4 m); loam; moderate, medium subangular blocky to strong fine subangular blocky;slightly hard, firm, slightly sticky; few, fine and medium roots; common, very fine pores; very thin, common, clay skins; clear, smooth boundary; 7-10 cms thick, pH 5.7.
5	IICk1	35-70	Light gray (10YR 7/2 d) and pale brown (10YR 6/3 m); loam; strong, medium subangular blocky; very few, fine roots; slightly hard, firm, slightly sticky; common, very fine pores; common, very thin clay skins; clear, smooth boundary; 12-20 cms thick; strongly effervescent; pH 7.0.
6	IICk2	70-110+	Light brownish gray (10YR 6/2 d) and grayish brown (10YR 5/2 m); sandy loam; amorphous; loose, very friable; strongly effervescent; pH 7.1.

Pedon L1 Results of routine analysis

Sample No.	Depth (cms)	Horizon		Particle Size Distribution (<2mm) (% finer than)										
				Sand						Silt			Clay	
				2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
1	6-0	F-H		-	-	-	-	-	-	-	-	-	-	-
2	0-6	Ae		100.0	100.0	99.8	99.1	89.5	75.4	65.4	43.5	11.2	4.7	0.5
3	6-17	Bf		100.0	99.4	98.4	97.2	92.6	78.8	67.8	56.2	19.9	9.5	2.3
4	17-35	IIBm		100.0	97.1	93.5	89.8	80.2	73.5	70.2	64.3	43.5	26.8	3.5
5	35-70	IICk1	a)	100.0	98.5	96.3	93.9	87.4	80.7	77.8	61.6	37.1	22.4	3.6
			b)*	100.0	98.1	95.6	92.5	85.0	78.8	76.7	66.3	50.6	35.3	8.2
6	70-110+	IICk2	a)	100.0	89.5	78.3	69.1	51.4	35.4	30.5	16.4	9.8	7.1	3.8
			b)*	100.0	89.2	79.7	73.1	61.7	48.1	44.4	27.4	15.6	10.0	2.6

* particle size distribution after carbonate removal from the sample.

Pedon L1

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay < 0.002 mm	% f.Clay < 0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. > 2 mm	Db g/cc < 2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
1	-	-	-	-	-	-	-	-	-	4.5
2	30	65	5	1	SiL	SiL	0	1.00	-	4.6
3	27	63	10	2	SiL	SiL	0	0.71	-	5.0
4	28	45	27	4	L-CL	L	11	1.71	-	5.7
5	20	58	22	4	SiL	L	21	1.89	41.5	7.0
6	67	26	7	4	SL	SL	64	1.75	59.6	7.1

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{tot. clay}$
1	F-H	30.8	-	-	-	-	-	-	-	-	-	-	-
2	Ae	3.2	0.17	18.8	0.10	0.08	4.94	1.13	9.7	0.03	0.04	0.07	0.014
3	Bf	6.8	0.41	16.5	0.19	0.07	15.69	2.56	53.6	0.74	0.98	1.72	0.172
4	IIBm	0.9	0.07	12.8	0.06	0.10	10.63	2.05	12.7	0.18	0.08	0.26	0.009
5	IICk1	-	-	-	-	-	-	-	-	0.01	0.00	0.01	0.045
6	IICk2	-	-	-	-	-	-	-	-	0.01	0.00	0.01	0.001

Vegetation Description*

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	18	10-20 m	28
	A2	10	5-10 m	
Shrub	B1	15	2- 5 m	45
	B2	30	$<$ 2 m	
Herb	Ch	1	herbaceous	43
	Cw	42	dwarf shrub	
Moss	Db	20	mosses	23
	Dl	3	lichens	

Epiphytes: Scarce.

Forest stand: DBH range: 5-40 cms, mean 20 cms; average height: 12 m; largest tree in plot: 18 m; DBH 40 cms, age 300 years; regeneration: strong, species *Abies lasiocarpa*.

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*Compiled at all sites by D.M. Smith and I.G.W. Corns.

Species List Site No. L1

LYR	SPECIES	% COVER
A1	*Picea engelmanni*	15
	Abies lasiocarpa	3
A2	*Picea engelmanni*	2
	Abies lasiocarpa	8
B1	*Abies lasiocarpa*	15
B2	*Abies lasiocarpa*	30
	Salix glauca	2
Ch	*Pedicularis bracteosa*	+*
	Carex pyrenaica	+
	Pyrola secunda	+
	Eqiusetum scirpoides	+
	Carex concinna	+
Cw	*Phyllodoce glandulifera*	35
	Vaccinium scoparium	7
Db	*Hylocomium splendens*	15
	Dicranum splendens	5
	Peltiera aphthosa	+
	Peltigera canina	+
	Pohlia nutans	+
	Drepanocladus uncinatus	+
	Barbilophozia lycopodioides	+
	Barbilophozia hatcheri	+
D1	*Cladonia alpestris*	+
	Cladonia centotea	+
	Cladonia gracilis	+
	Cladonia chlorophaea	+

* + = present at site, less than 1% cover.

PEDON NO. L2 Date described: August 30, 1977.

Location:	Site located about 20 m behind meteorological plot adjacent to Parker's Ridge Youth Hostel.
Military Grid Co-Ordinates:	11 U MH 912 821.
Landform Classification:	Eolian veneer/sorted inclined moraine.
Parent Material:	Fine loamy and fine silty, mixed volcanic ash and local detritus/coarse loam and sandy extremely calcareous mixed sedimentary.
Site form:	Regular.
Seepage:	Absent.
Drainage:	Well drained.
Solum thickness:	45 cms.
Elevation:	2030 m. asl.
Slope:	6%, slightly concave.
Sample site position:	Lower slope.
Aspect:	North.
Classification:	Orthic Humo-Ferric Podzol (lacks Bf horizon 10 cm thick, see page 109).

Sample No.	Horizon	Depth (cms)	
7	L-H	3-0	Brownish black (7.5YR 2/2 d) and (5 YR 2/1 m); semi and well decomposed litter; fibrous mat; abundant roots of all sizes; abrupt, smooth boundary; 2-5 cms thick; pH 4.5.
8	Ae	0-7	Pinkish gray (7.5YR 2/2 d) and reddish gray (5YR 5/2 m); silt loam; weak, fine platy; loose, non sticky; plentiful, very fine to medium roots; few, very fine pores; abrupt wavy boundary; 6-10 cms thick; pH 4.6.
9	Bf	7-14	Brown (7.5YR 5/4 d) and dark reddish brown (5YR 3/3 m); silt loam; moderate, medium subangular blockly to moderate, fine platy; loose, non sticky; few, very fine and fine roots; few, very fine pores; clear, wavy boundary; 6-10 cms thick; pH 4.7.
10	IIBm	14-24	Yellow (10YR 7/6 d) and brown (10YR 4/6 m); silt loam to loam; moderate, medium subangular blocky to strong fine subangular blocky; soft, very friable, slightly sticky; few fine and medium roots; many, very fine pores; few, very thin clay skins; clear, smooth boundary; 8-13 cms thick; pH 4.8.
11	IICk1	24-35	Light grayish brown (10YR 6/2 d) and (10YR 4/2 m); sandy loam; weak, fine subangular blocky; loose, non sticky; few, fine roots; few, very fine pores; clear, wavy boundary; 18-25 cms thick; strongly effervescent; pH 6.8.
12	IICk2	45-90+	Light grayish brown (10YR 6/2 d) and dark gray (10YR 4/1 m); sandy loam; amorphous; loose, non sticky; strongly effervescent; pH 7.1.

Pedon L2 Results of routine analysis

			Particle Size Distribution (<2mm) (% finer than)										
			Sand						Silt			Clay	
Sample No.	Depth (cms)	Horizon	2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
7	3-0	L-H	-	-	-	-	-	-	-	-	-	-	-
8	0-7	Ae	100.0	99.6	99.2	97.8	89.9	48.1	72.8	58.3	17.8	9.5	1.9
9	7-14	Bf	100.0	99.5	98.6	97.7	95.0	83.2	69.5	56.3	17.9	9.0	1.3
10	14-24	IIBm	100.0	97.0	93.1	87.9	76.2	66.5	62.2	52.6	33.0	21.2	3.1
11	24-45	IICk1	100.0	98.3	95.3	86.9	61.7	40.1	34.7	19.4	10.9	7.2	1.5
12	45-90+	IICk2	100.0	82.3	72.1	61.5	44.7	33.4	30.5	17.8	9.2	5.2	1.3

Pedon L2

Sample No.	% sand 2.0–0.05 mm	% silt 0.05–0.002 mm	% Clay <0.002 mm	% f.Clay <0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. >2 mm	Db g/cc <2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
7	-	-	-	-	-	-	-	-	-	4.5
8	24	66	10	2	SiL	SiL	0	0.88	-	4.6
9	23	68	9	1	SiL	SiL	3	0.63	-	4.7
10	36	43	21	3	L	SiL	17	1.42	0.3	4.8
11	63	30	7	2	SL	SL	64	1.49	70.0	6.8
12	68	27	5	1	SL	SL	75	1.65	80.0	7.1

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{\text{tot. clay}}$
7	L-H	29.15	-	-	-	-	-	-	-	-	-	-	-
8	Ae	3.12	0.22	14.2	0.14	0.13	4.56	1.74	12.1	-	-	-	-
9	Bf	6.32	0.35	18.1	0.20	0.17	5.75	2.36	34.7	0.77	1.12	1.89	0.200
10	IIBm	1.00	0.06	16.7	0.13	0.08	3.94	2.15	11.2	0.35	0.14	0.49	0.023
11	IICk1	-	-	-	-	-	-	-	-	0.06	0.03	0.09	0.013
12	IICk2	-	-	-	-	-	-	-	-	-	-	-	-

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	10	10-17 m	17
	A2	7	5-10 m	
Shrub	B1	10	2- 5 m	15
	B2	5	$<$ 2 m	
Herb	Ch	1	herbaceous	61
	Cw	60	dwarf shrub	
Moss	Db	10	mosses	13
	Dl	3	lichens	

Ephiphytes: Scarce. (*Alectoria* sp.)

Forest stand: DBH range: 5-55 cms, mean (est) 30 cms; average height of forest canopy: 12 m; largest tree in the plot: height 15 m, DBH 55 cms; regeneration: strong, species *Picea engelmanni*; successional stage: mature. Remarks: A1 stratum dominated by *Picea*, however B strata show dominance by *Abies lasiocarpa*.

Species List — Site No. L2

LAYER	SPECIES	% COVER
A1	*Picea engelmanni*	8
	Abies lasiocarpa	2
A2	*Picea engelmanni*	2
	Abies lasiocarpa	5
B1	*Abies lasiocarpa*	10
B2	*Abies lasiocarpa*	5
	Salix arctica	2
Ch	*Senecio triangularis*	+
	Erigeron perigrinus	+
	Arnica latifolia	+
	Antennaria lanata	+
	Pyrola secunda	+
	Anemone sp.	+
Cw	*Vaccinium scoparium*	45
	Phyllodoce empetreformis	1
	Phyllodoce glandulifera	15
	Cassiope mertensiana	5
Db	*Hylocomium splendons*	+
Dl	*Cladonia alpestris*	+
	Cladonia pyxidata	+
	Cladonia chlorophaea	+
	Peltiqua apthosa	+
	Tortula ruralis	+
	Centraria islandica	+

Photographs of L3 site and profile.

<u>PEDON L3</u> Date described: August 30, 1977.

Location:	Site located in an opening approximately 150 m northwest from the start of the Parker's Ridge hiking trail.
Military Grid Co-ordinates:	11 U MH 916 819.
Landform Classification:	Eolian veneer/inclined moraine.
Parent Material:	Coarse silty, mixed volcanic ash and local detritus/coarse loamy, extremely calcareous mixed sedimentary.
Site form:	Regular - slightly concave.
Seepage:	Absent (intermittently present during snow melt).
Drainage:	Well drained.
Solum thickness:	50 cms.
Elevation:	2,060 m. asl.
Slope:	10%, simple.
Sample site position:	Lower slope.
Aspect:	North-northeast.
Classification:	Orthic Humo-Ferric Podzol (lacks Bf horizon 10 cm thick, see page 109).

Sample No.	Horizon	Depth (cms)	
13	F-H	6-0	Brownish black (7.5YR 2/2 d) and black (7.5YR 2/1 m); semi-decomposed organic matter, fibrous mat, much charcoal; abundant fine and medium roots; few coarse roots; abrupt, smooth boundary; 5-8 cms thick; pH 4.4.
14	Ae	0-12	Light gray (5YR 7/1 d) and dark brown (7.5YR 4/2 m); silt loam; weak medium platy to weak fine platy; loose, non sticky; plentiful, very fine, fine and medium roots, very few coarse roots; common, very fine pores; gradual, smooth boundary; 10-15 cms thick; pH 4.4.
15	Bf	12-20	Brown (7.5YR 5/4 d) and dark reddish brown (5YR 2/3 m); silt loam; weak, medium subangular blocky to weak, fine platy; soft, very friable, non sticky; few, medium and fine roots; common, very fine pores; clear, broken boundary; 0-10 cms thick; pH 4.7.
15	IIBm1	20-35	Light yellowish brown (10YR 6/4 d) and light brown (7.5YR 6/4 m); loam; moderate, medium subangular blocky to strong, fine subangular blocky; slightly hard, very friable, slightly sticky; few medium and fine roots; common, very fine pores; common, very thin to thin clay skins; clear, smooth boundary; 12-20 cms thick; pH 5.3.
17	IIBm2	35-50	Light yellowish brown (10YR 6/4 d) and (10YR 5/4 m); clay loam to loam, moderate, medium to fine subangular blocky; slightly hard, firm, slightly sticky; few fine roots, very few medium roots; common, very fine pores; few, very thin clay skins; clear, smooth boundary; 12-25 cms thick; pH 6.1.
18	IICk1	50-75	Light gray (10YR 7/2 d) and dark yellowish brown (10YR 4/4 m); clay loam to loam; weak, medium subangular blocky; soft, friable, slightly sticky; few, very fine pores; few, very thin clay skins; gradual smooth boundary; 20-30 cms thick, moderately effervescent; pH 6.9.
19	IICk2	75-100+	Light gray (10YR 7/2 d) and yellowish brown (10YR 5/4 m); loam; amorphous, loose, slightly sticky; strongly effervescent; pH 7.1.

Pedon L3 Results of routine analysis

Sample No.	Depth (cms)	Horizon		Particle Size Distribution (<2mm) (% finer than)										
				Sand						Silt			Clay	
				2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
13	6-0	F-H		-	-	-	-	-	-	-	-	-	-	-
14	0-12	Ae		100.0	99.5	99.0	96.8	89.1	77.6	72.2	55.2	16.3	6.9	1.9
15	12-20	Bf		100.0	99.5	98.9	98.3	95.8	84.5	71.5	56.2	17.8	9.8	1.7
16	20-35	IIBm1		100.0	96.9	93.3	89.8	83.7	75.2	71.0	59.1	36.2	22.5	4.0
17	35-50	IIBm2		100.0	98.2	96.1	93.8	89.6	82.4	78.6	65.3	43.2	28.1	5.0
18	50-75	IICk1	a)	100.0	93.6	88.1	84.0	78.4	70.2	62.9	40.3	22.6	7.3	3.9
			b)*	100.0	91.5	87.2	-	80.3	72.7	69.4	48.4	31.5	22.0	6.6
19	75-100+	IICk2	a)	100.0	77.6	68.3	59.5	48.3	39.1	36.2	22.4	9.8	6.0	0.7
			b)*	100.0	96.7	94.0	91.9	87.4	78.4	74.5	58.0	33.1	20.5	5.9

* particle size distribution after carbonate removal.

Pedon L3

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay <0.002 mm	% f.Clay <0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. >2 mm	Db g/cc <2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
13	-	-	-	-	-	-	-	-	-	4.4
14	25	68	7	2	SiL	SiL	0	0.91	-	4.4
15	22	68	10	2	SiL	SiL	5	0.69	-	4.7
16	27	50	23	4	SiL-L	L	24	1.18	-	5.3
17	20	52	28	5	SiCL-L	CL	40	1.21	3.4	6.1
18	33	60	7	4	SiL	CL	62	1.65	40.0	6.9
19	62	32	6	1	SL	L	55	-	58.2	7.1

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{\text{tot. clay}}$
13	F-H	30.01	-	-	-	-	-	-	-	-	-	-	-
14	Ae	3.82	0.18	21.2	0.13	0.12	3.00	1.02	10.9	0.06	0.12	0.18	0.026
15	Bf	5.78	0.36	16.1	0.21	0.13	7.81	1.64	38.2	0.72	0.99	1.71	0.171
16	IIBm1	1.55	0.08	19.4	0.12	0.06	8.06	2.15	12.7	0.29	0.13	0.42	0.018
17	IIBm2	2.04	0.10	20.4	0.10	0.10	13.13	4.51	11.8	0.21	0.07	0.28	0.010
18	IICk1	-	-	-	-	-	-	-	-	0.07	0.02	0.09	0.013
19	IICk2	-	-	-	-	-	-	-	-	0.06	0.01	0.07	0.012

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	14	10-20 m	15
	A2	1	5-10 m	
Shrub	B1	1	2- 5 m	6
	B2	5	$<$ 2 m	
Herb	Ch	7	herbaceous	65
	Cw	58	dwarf shrub	
Moss	Db	15	mosses	17
	Dl	2	lichens	

Epiphytes: Scarce (*Alectoria* sp.)

Forest stand: DBH range: 5-67 cms; mean (est): 45 cms; average height of forest canopy: 10 m; largest tree in the plot: height 18 m, DBH 46 cms; age $\approx$ 300 years; regeneration: strong *Abies lasiocarpa*, weak *Picea engelmanni*; successional stage: mature. Remarks: forest very open, site located in 15 m opening, ground hummocky, stunted tree growth.

Species List

Site No. L3

LAYER	SPECIES	% COVER
A1	Picea engelmanni	10
	Abies lasiocarpa	4
A2	Abies lasiocarpa	1
	Picea engelmanni	+
B1	Abies lasiocarpa	1
B2	Abies lasiocarpa	2
	Salix arctica	2
	Salix vestita	1
C1	Senecio triangularis	2
	Anemone sp.	+
	Erigeron perigrinus	+
	Pedicularis bracteosa	2
	Arnica latifolia	+
	Sibbaldia procumbens	+
	Antennaria lanata	+
	Antemisia rorvegue	+
Cw	Cassiope mertensiana	30
	Phyllodoce glandulifera	10
	Vaccinium scoparium	18
Db	Barbilophozea hatcheri	8
	Dicranum sp.	4
Dl	Peltigera apthosa	+
	Peltigera sp.	1
	Cladonia cariosa	1
	Cladonia verticillata	1
	Cladonia ecmocyna	1
	Cetraria pinastri	+
	Cetraria islandica	+
	Alectoria glabra	+

PEDON NO. P1 | Date described: August 29, 1977.

Location:	10 m due west of small knob located 200 m south (traversed parallel to the slope) from Site L1.
Military Grid Co-ordinates:	11 U MH 861 848.
Landform Classification:	Washed eolian veneer/inclined hummocky moraine.
Parent Material:	Coarse silty, mixed volcanic ash and local detritus/coarse loamy, extremely calcareous, mixed sedimentary.
Site form:	Irregular - concave.
Seepage:	Intermittently present.
Drainage:	Moderately well - well.
Solum thickness:	44 cms.
Elevation:	2,030 m. asl.
Slope:	5%, complex.
Sample site position:	Middle - lower slope.
Aspect:	East-northeast.
Classification:	Orthic Humo-Ferric Podzol.

Sample No.	Horizon	Depth (cms)	
20	F-H	7-0	Dark brown (7.5YR 3/2 d) and dark reddish brown (5YR 2/2 m); semi to well decomposed organic matter; abundance of twigs, needles, and humus material; fibrous, abundant fine and medium roots; abrupt, smooth boundary, 5-10 cms thick; pH 4.2.
21	Ae	0-9	Pinkish white (7.5YR 8/2 d) and brown (7.5YR 5/2 m); silt loam; moderate fine platy; soft, very friable, non sticky; plentiful very fine and fine roots, few medium and coarse roots; few very fine pores, clear, smooth boundary; 6-10 cms thick; pH 4.2.
22	Bf	9-17	Strong brown (7.5YR 5/6 d) and dark reddish brown (5YR 3/4 m), silt loam, moderate fine platy to moderate fine subangular blocky; soft, very friable, non sticky; few, fine and medium roots; few, very fine pores, abrupt, smooth boundary; 8-11 cms thick; pH 4.3.
23	Bm	17-28	Light yellowish brown (10YR 6/4 d) and dark yellowish brown (10YR 4/4 m); silt loam-loam; weak fine subangular blocky; slightly hard, friable, slightly plastic; few, fine and very few medium roots; many, very fine pores; clear, smooth boundary; 9-12 cms thick; pH 4.3.
24	IIBC	28-44	Light yellowish brown (10YR 6/4 d) and dark yellowish brown (10YR 3/4 m); fine sandy loam; moderate fine subangular blocky; soft, very friable, non sticky; very few fine roots; many, very fine and fine pores; abrupt, smooth boundary; 15-20 cms thick; weakly effervescent; pH 6.1.
25	IICk1	44-65	Light gray (2.5YR 7/2 d) and light yellowish brown (2.5YR 6/4 m); clay loam-loam; strong medium subangular blocky, slightly hard, friable, slightly sticky; common, fine pores; clear, smooth boundary; extremely effervescent; pH 6.8.
26	IICk2	65-90+	Pale brown (10YR 6/3 d) and dark grayish brown (10YR 4/2 m); sandy loam; amorphous; loose, non sticky; few, very fine pores; extremely effervescent; pH 7.1.

Pedon P1 Results of routine analysis

Sample No.	Depth (cms)	Horizon	Particle Size Distribution (<2mm) (% finer than)										
			Sand						Silt			Clay	
			2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
20	7-0	F-H	-	-	-	-	-	-	-	-	-	-	-
21	0-9	Ae	100.0	99.9	99.7	98.8	87.9	71.4	61.9	47.3	10.7	4.3	0.5
22	9-17	Bf	100.0	97.8	93.0	86.2	75.9	64.5	56.3	47.2	18.0	9.5	2.6
23	17-28	Bm	100.0	98.6	95.5	87.9	68.3	54.9	50.2	38.4	22.6	15.6	2.9
24	28-44	IIBC	100.0	95.8	82.9	66.4	49.6	38.8	34.8	23.9	12.3	7.9	1.3
25	44-65	IICk1	100.0	97.0	93.7	90.2	84.9	80.3	78.8	68.9	40.4	23.4	4.1
26	65-90+	IICk2	100.0	95.5	89.2	75.2	44.6	32.3	28.3	18.1	8.0	3.9	0.3

Pedon P1

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay <0.002 mm	% f.Clay <0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. >2 mm	Db g/cc <2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
20	-	-	-	-	-	-	-	-	-	4.2
21	34	62	4	1	SiL	SiL	0	0.79	-	4.2
22	40	50	10	3	SiL-L	SiL	5	0.64	-	4.3
23	48	36	16	3	L	SiL	3	1.34	-	4.3
24	63	29	8	1	SL	SL	5	1.21	2.6	6.1
25	21	56	23	4	SiL	CL	52	1.79	52.6	6.8
26	70	26	4	0	SL	SL	10	1.71	51.1	7.0

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{\text{tot. clay}}$
20	F-H	42.58	-	-	-	-	-	-	-	-	-	-	-
21	Ae	2.35	0.13	18.1	0.12	0.08	3.25	0.82	7.6	-	-	-	-
22	Bf	5.24	0.26	20.2	0.18	0.05	4.44	1.43	39.4	0.52	0.91	1.43	0.143
23	Bm	1.01	0.05	20.2	0.09	0.05	2.56	1.33	12.1	0.29	0.13	0.42	0.026
24	IIBC	1.54	0.06	25.6	0.10	0.09	10.88	2.66	9.4	0.21	0.08	0.29	0.036
25	IICk1	-	-	-	-	-	-	-	-	-	-	-	-
26	IICk2	-	-	-	-	-	-	-	-	-	-	-	-

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	15	10-15 m	20
	A2	5	5-10 m	
Shrub	B1	15	2- 5 m	60
	B2	45	$<$ 2 m	
Herb	Ch	4	herbaceous	29
	Cw	25	dwarf shrub	
Moss	Db	13	mosses	20
	Dl	7	lichens	

Epiphytes: Scarce.

Forest stand: DBH range: 10-48 cms, mean (est) 30 cms; average height of forest canopy: 10 m; largest tree in the plot: height 15 m, DBH 48 cms, age 300 years; regeneration: moderate, species Abies lasiocarpa, Picea engelmanni, Pinus contorta; successional stage: mature.

Species List

Site No. P1

LAYER	SPECIES	% COVER
A1	*Picea engelmanni*	12
	Abies lasiocarpa	3
A2	*Picea engelmanni*	2
	Abies lasiocarpa	3
	Pinus contorta	+
B1	*Abies lasiocarpa*	13
	Picea engelmanni	2
B2	*Abies lasiocarpa*	40
	Salix barrattiana	3
	Salix vestita	2
C1	*Pedicularis bracteosa*	2
	Dryas octopetala	+
	Castilleja miniata	+
	Poa sp.	+
	Pyrola secunda	+
	Equisetum scirpoides	+
Cw	*Phylladoce glandulifera*	15
	Phylladoce empetriformis	3
	Cassiope mertensiana	2
	Cassiope tetragona	1
	Vaccinium scoparium	5
Db	*Dicranum* sp.	2
	Hylacomeum splendins	8
	Barbilophozia lycopodioides	3
D1	*Cladonia pyxidata*	+
	Peltiqera aphthosa	3
	Crustosa sp.	+
	Tortula ruralis	

PEDON NO. P2 Date described: August 30, 1977.

Location:	Approximately 500 m up the north bank of the first creek located along the slope (about 1 km) south of Banff-Jasper boundary.
Military Grid Co-Ordinates:	11 U MH 899 830.
Landform Classification:	Eolian veneer/inclined moraine.
Parent Material:	Coarse silty, mixed volcanic ash and local detritus/coarse loamy, extremely calcareous mixed sedimentary.
Site form:	Regular.
Seepage:	Absent.
Drainage:	Well drained.
Solum thickness:	50 cms.
Elevation:	2,130 m. asl.
Slope:	17%, simple.
Sample site position:	Upper - middle slope.
Aspect:	Northeast.
Classification:	Orthic Humo-Ferric Podzol.
Remarks:	Till parent material extremely bouldery.

Sample No.	Horizon	Depth (cms)	
27	L-F-H	3-0	Dark brown (7.5YR 3/2 d); undecomposed litter and twigs through to well decomposed humus material, fibrous mat; abundant roots of all sizes; abrupt smooth boundary; 2-5 cms thick; pH 4.7.
28	Ae	0-13	Pinkish gray (7.5YR 7/2 d) and dark brown (7.5YR 4/2 m); silt loam; weak, very fine platy; soft, very friable, non sticky; plentiful, very fine, fine and medium roots, few coarse roots; common, very fine pores; clear, smooth boundary; 10-15 cms thick; pH 4.5.
29	Bf	13-25	Strong brown (7.5YR 5/6 d) and dark reddish brown (5YR 3/4 m); silt loam; moderate fine platy and weak fine subangular blocky; soft, very friable, non sticky; plentiful fine roots, few very fine and medium roots; common, very fine pores; clear smooth boundary; 10-15 cms thick; pH 5.5.
30	IIBCk	25-50	Yellowish brown (10YR 5/6 d) and dark brown (7.5YR 4/4 m); loam to sandy loam; moderate fine subangular blocky; very few medium roots; common, very fine and fine pores; few, very thin clay skins; clear, smooth boundary; 20-30 cms thick; pH 6.8.
31	IICk	50-90+	Light yellowish brown (10YR 6/4 d) and dark yellowish brown (10YR 4/4 m); loam; amorphous; slightly hard, very friable, slightly sticky; few, very fine pores; extremely effervescent; pH 7.0.

Pedon P2 Results of routine analysis

Sample No.	Depth (cms)	Horizon		Particle Size Distribution (<2mm) (% finer than): Sand 2.0 mm	Sand 1.0 mm	Sand 0.50 mm	Sand 0.25 mm	Sand 0.105 mm	Sand 0.053 mm	Silt 0.047 mm	Silt 0.020 mm	Silt 0.005 mm	Clay 0.002 mm	Clay 0.0002 mm
27	3-0	L-F-H		-	-	-	-	-	-	-	-	-	-	-
28	0-13	Ae		100.0	99.9	99.6	98.5	95.0	77.2	68.2	46.4	9.7	3.6	0.9
29	13-25	Bf		100.0	99.4	98.6	97.4	92.0	76.6	63.3	51.5	15.4	6.8	1.0
30	25-50	IIBCk		100.0	95.6	89.8	81.6	70.4	61.2	57.5	46.5	22.3	11.1	0.4
31	50-90+	IICk1	a)	100.0	78.8	66.2	55.6	-	40.5	38.9	25.1	12.5	5.8	0.5
			b)*	100.0	89.3	81.2	72.8	64.1	56.1	53.8	39.7	21.5	11.4	1.8

* particle size distribution after removal of carbonates.

Pedon P2

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay <0.002 mm	% f.Clay <0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. >2 mm	Db g/cc <2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
27	-	-	-	-	-	-	-	-	-	4.7
28	27	69	4	1	SiL	SiL	0	0.87	-	4.5
29	30	63	7	1	SiL	SiL	2	0.73	-	5.5
30	41	48	11	0	L	L-SL	50	1.13	11.0	6.8
31	60	34	6	1	SL	L	80	1.50	47.0	7.0

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{\text{tot. clay}}$
27	L-F-H	43.05	-	-	-	-	-	-	-	-	-	-	-
28	Ae	2.87	0.18	15.9	0.27	0.08	1.63	0.61	9.4	0.11	0.12	0.23	0.058
29	Bf	5.19	0.26	20.0	0.17	0.24	17.94	3.89	42.9	0.38	0.49	0.87	0.124
30	IIBCk	2.65	0.12	22.1	0.12	0.29	20.88	4.00	16.5	0.24	0.14	0.38	0.035
31	IICk	-	-	-	-	-	-	-	-	0.12	0.03	0.15	0.025

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	15	10-12 m	30
	A2	15	5-10 m	
Shrub	B1	5	2- 5 m	20
	B2	15	$<$ 2 m	
Herb	C1	1	herbaceous	41
	Cw	40	dwarf shrub	
Moss	Db	25	mosses	30
	D1	5	lichens	

Epiphytes: Scarce.

Forest stand: DBH range: 5-28 cms, mean (est) 20 cms; average height of forest canopy: 8 m; largest tree in the plot: height 12 m, DBH range 28 cms, age $\approx$ 300 years; regeneration: strong, species *Abies lasiocarpa*; successional stage: mature.

Species List

Site No. P2

LAYER	SPECIES	% COVER
A1	Picea engelmanni	12
	Abies lasiocarpa	3
A2	Picea engelmanni	4
	Abies lasiocarpa	11
B1	Picea engelmanni	1
	Abies lasiocarpa	4
B2	Abies lasiocarpa	15
Ch	Arnica cordifolia	1
	Erigeron perigrinus	+
	Pedicularis bracteosa	+
Cw	Cassiope mertensiana	20
	Phyllodoce glandulifera	15
	Cassiope tetragona	2
	Vaccinium scoporium	5
	Phyllodoce empetriformis	+
Db	Barbilophozia hatcheri	5
	Dicranum sp.	5
	Hylocomium splendens	15
	Peltigera canina	
	Peltigera apthosa	
	Pohlia nutons	
	Hypnum sp.	
Dl	Cladonia ecmocyna	)
	Cladonia gonecha	) 4
	Cladonia cenotea	)
	Cladonia sp.	)
	Cetraria islandica	+
	Lepraria neglecta	+

PEDON NO. B1

Date described: September 1, 1977.

Location:	30 m south along slope from Site L1 behind Brewster's camp.
Military Grid Co-ordinates:	11 U MH 855 847.
Landform Classification:	Washed fluvioeolian veneer/inclined moraine.
Parent Material:	Coarse silty and coarse loamy, neutral to weakly calcareous mixed local detritus/ coarse loamy, extremely calcareous, mixed sedimentary till.
Site form:	Regular.
Seepage:	Generally absent, evidence of intermittent seepage.
Drainage:	Moderately well drained.
Solum thickness:	34 cms.
Elevation:	2,000 m asl.
Slope:	8%, simple.
Sample site position:	Middle slope.
Aspect:	North-northeast.
Classification:	Cumulic Regosol.
Remarks:	Site shows fluvial disturbance, small (2 cm thick) buried Ah horizon, no Ae or Bf horizons.

Sample No.	Horizon	Depth (cms)	
32	F-H	5-0	Dark brown (7.5YR 3/2 d) and (7.5YR 2/2 m); semi and well decomposed organic matter, fibrous; abundant roots of all sizes; abrupt, smooth boundary; 3-6 cms thick; pH 6.4.
33	Bm	0-12	Brown (10YR 5/3 d) and dark brown (7.5 YR 4/4 m); silt loam to fine sandy loam; weak, medium subangular blocky; soft, very friable, non sticky; abundant fine and medium, few, coarse roots; few, very fine pores, abrupt wavy boundary; 10-15 cms thick; pH 6.5.
Not Sampled	Ahb	12-14	Black (5YR 2/1 m); buried well decomposed organic matter and mineral material; few, medium roots; abrupt wavy boundary; 2-3 cms thick.
34	Bmb	14-34	Light yellowish brown (10YR 6/4 d) and dark brown (7.5YR 4/4 m); silt loam to fine sandy loam; weak, medium to fine subangular blocky; soft, friable, non sticky; few fine and medium roots; few, very fine pores; gradual smooth boundary; 8-12 cms thick; pH 6.5.
35	IICk1	34-50	Very pale brown (10YR 7/3 d) and dark yellowish brown (10YR 4/4 m); fine sandy loam to loam; weak moderate and fine subangular blocky; slightly hard, friable, non sticky; few, very fine pores; gradual, smooth boundary, moderately effervescent; pH 7.0.
36	IICk2	50-90+	Very pale brown (10YR 8/3d) and pale brown (10YR 6/3 m), loam; amorphous; slightly hard, friable, slightly sticky; strongly effervescent; pH 7.3.

Pedon B1 Results of routine analysis

			Particle Size Distribution (<2mm) (% finer than)										
			Sand						Silt			Clay	
Sample No.	Depth (cms)	Horizon	2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
32	5-0	F-H	-	-	-	-	-	-	-	-	-	-	-
33	0-12	Bm	100.0	99.7	98.3	93.4	78.9	65.9	60.3	50.6	22.5	10.1	0.9
34	14-34	Bmb	-	-	-	-	-	-	-	-	-	-	-
35	34-50	Ck1	100.0	93.5	88.2	82.1	66.8	54.2	49.4	35.0	16.9	8.7	1.1
36	50-90	Ck2	100.0	80.9	68.5	58.7	50.5	45.8	44.6	38.9	23.6	14.1	2.6

Pedon B1

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay <0.002 mm	% f.Clay <0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. >2 mm	Db g/cc <2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
32	-	-	-	-	-	-	-	-	-	6.4
33	36	54	10	1	SiL	SiL-SL	0	0.78	-	6.5
34	-	-	-	-	-	SiL-SL	16	1.20	-	6.5
35	48	43	9	1	L	SL-L	44	1.82	23.0	7.0
36	55	31	14	3	SL	L	57	1.90	40.0	7.3

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{\text{tot. clay}}$
32	F-H	35.87	-	-	-	-	-	-	-	-	-	-	-
33	Bm	3.58	0.26	13.8	0.15	0.10	22.56	3.07	24.7	0.25	0.24	0.49	0.049
34	Bmb	2.49	0.18	13.8	0.11	0.08	20.63	3.38	22.4	0.15	0.16	0.31	0.031
35	IICk1	-	0.06	-	-	-	-	-	-	-	-	-	-
36	IICk2	-	-	-	-	-	-	-	-	-	-	-	-

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	5	10-15 m	10
	A2	5	5-10 m	
Shrub	B1	5	2- 5 m	55
	B2	50	$<$ 2 m	
Herb	Ch	20	herbaceous	32
	Cw	12	dwarf shrub	
Moss	Db	15	mosses	16
	Dl	1	lichens	

Epiphytes: Scarce.

Forest stand: DBH range: 5-40 cms, mean (est): 20 cms; average height of forest canopy: 8 m; largest tree in the plot: height 15 m, DBH 40 cms, age undetermined; regeneration: weak, species *Abies lasiocarpa*, *Pieca engelmanni*.
Remarks: Somewhat mixed tree species - *Pinus contorta*. Disturbed site is floristically rich.

Species List

Site No. Bl

LAYER	SPECIES	% COVER
Al	Picea engelmanni	3
	Abies lasiocarpa	1
	Pinus contorta	1
A2	Picea engelmanni	1
	Abies lasiocarpa	4
Bl	Picea engelmanni	1
	Abies lasiocarpa	4
B2	Abies lasiocarpa	20
	Salix vestita	15
	Salix glauca	15
	Salix barrattiana	5
	Potentilla fruticosa	20
	Juniperus communis	7
Cl	Dryas octopetala	3
	Solidago multiradiata	1
	Senecio sp.	1
	Erigeron perigrinus	1
	Pyrola asarifolia	1
	Trollius albiflorus	1
	Pedicularis bracteosa	1
	Carex sp.	2
	Elymus innovatus	2
	Equisetum variegatum	+
	Anemone parviflora	1
	Pyrola virens	+
	Hedysarum mackenzii	+
	Antennaria racemosa	1
	Castilleja occidentalis	+
	Carex cancimna	+
	Silene acaulis	+
Cw	Phyllodoce glandulifera	25
	Cassiope mertensiana	+
	Vaccinium scoparium	7
Db	Tortula sp.	8
	Dicranum sp.	7
Dl	Cladonia pyxidata	1

PEDON NO. B2

Date described: September 1, 1977.

Location:	Site located 150 m up the Banff-Jasper boundary cutline, then in about 20 m on the left hand side.
Military Grid Co-ordinates:	11 U MH 888 843.
Landform Classification:	Eolian veneer/inclined moraine.
Parent Material:	Coarse silty, mixed volcanic ash and local detritus/coarse loamy, extremely calcareous, mixed sedimentary.
Site form:	Convex.
Seepage:	Absent.
Drainage:	Well drained.
Solum thickness:	27 cms.
Elevation:	2,060 m. asl.
Slope:	35%, simple.
Sample site position:	Middle slope.
Aspect:	North.
Classification:	Eluviated Eutric Brunisol.
Remarks:	Site located on steep slope, some evidence of past fire. Solum developed entirely within upper parent material.

Sample No.	Horizon	Depth (cms)	
37	L-F-H	7-0	Dark brown (7.5YR 3/2 d) and (7.5YR 2/2 m); semi-decomposed to well decomposed organic material, fibrous mat of needles, twigs and litter; abundant roots of all sizes; abrupt, wavy boundary; 5-10 cms thick; pH 4.1.
38	Ae	0-12	Light brownish gray (7.5YR 7/1 d) and dark brown (7.5YR 3/2 m); silt loam; weak, fine platy; soft, very friable, non sticky; few coarse roots, plentiful, fine and medium roots, few, very fine pores, some humus material from above mixed into this horizon; clear, smooth boundary; 10-12 cms thick; pH 5.1.
39	Bm	12-27	Light brown (7.5YR 6/4 d) and dark brown (7.5YR 4/3 m); silt loam; moderate, medium subangular blocky; slightly hard, friable, slightly sticky; plentiful, fine roots, few, very fine and medium roots; common, very fine pores; clear, smooth boundary; 15-20 cms; pH 6.2.
40	IICk1	27-45	Very pale brown (10YR 7/4 d) and yellowish brown (10YR 5/4 m); loam; moderate, medium and fine subangular blocky; slightly hard, friable, slightly sticky; few, fine and very fine pores; gradual, smooth boundary; 15-25 cms thick; moderately effervescent; pH 7.1.
41	IICk2	45-90+	Very pale brown (10YR 8/3 d) and pale brown (10YR 6/3 m); sandy loam; amorphous; slightly hard, friable, slightly sticky; few, very fine pores; extremely effervescent; pH 7.4.

Pedon B2 Results of routine analysis

Sample No.	Depth (cms)	Horizon	Particle Size Distribution (<2mm) (% finer than)										
			Sand						Silt			Clay	
			2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
37	7-0	L-F-H	-	-	-	-	-	-	-	-	-	-	-
38	0-12	Ae	100.0	99.6	99.2	97.1	89.4	78.6	73.8	55.2	15.3	7.5	2.8
39	12-27	Bm	100.0	97.6	94.7	91.9	86.7	74.8	54.1	46.8	16.7	7.7	1.2
40	27-45	IICk1	100.0	86.6	76.1	68.5	58.8	50.2	46.6	33.0	16.7	9.4	-
41	45-90+	IICk2	100.0	84.5	73.3	64.4	55.2	48.2	45.4	33.8	15.0	8.2	1.5

Pedon B2

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay <0.002 mm	% f.Clay <0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. >2 mm	Db g/cc <2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
37	-	-	-	-	-	-	-	-	-	4.1
38	34	59	7	3	SiL	SiL	0	0.80	-	5.1
39	36	56	8	1	SL	SiL	14	0.78	-	6.2
40	52	39	9	-	SL	L	71	1.08	49.2	7.1
41	53	39	8	2	SL	SL	67	1.66	55.4	7.4

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{tot. clay}$
37	L-F-H	36.45	-	-	-	-	-	-	-	-	-	-	-
38	Ae	5.04	0.27	18.6	0.21	0.12	13.06	2.15	22.9	-	-	-	-
39	Bm	3.18	0.21	15.1	0.14	0.14	28.06	4.20	34.7	0.18	0.27	0.45	0.056
40	IICk1	-	-	-	-	-	-	-	-	0.13	0.04	0.17	0.018
41	IICk2	-	-	-	-	-	-	-	-	-	-	-	-

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	15	10-18 m	30
	A2	15	5-10 m	
Shrub	B1	10	2- 5 m	35
	B2	25	$<$ 2 m	
Herb	Ch	1	herbaceous	26
	Cw	25	dwarf shrub	
Moss	Db	10	mosses	20
	Dl	10	lichens	

Epiphytes: Scarce.

Forest stand: DBH range: 5-32 cms, mean (est) 15 cms; average height of forest canopy: 5 m; largest tree in the plot: 10 m, DBH 32 cms; regeneration: strong, species *Abies lasiocarpa*; successional stage: mature. Remarks: Abundant layering of *Abies lasiocarpa*.

Species List

Site No. B2

LAYER	SPECIES	% COVER
A1	Picea engelmanni	12
	Abies lasiocarpa	3
A2	Picea engelmanni	3
	Abies lasiocarpa	11
	Pinus contorta	1
B1	Picea engelmanni	2
	Abies lasiocarpa	8
B2	Abies lasiocarpa	23
	Salix vestita	2
	Salix glauca	+
C1	Pedicularis bracteosa	+
	Oxyria digyna	+
	Carex sp.	+
	Dryas octopetala	+
	Castilleja miniata	+
	Erigeron perigrinus	+
	Cladonia gonecha	
	Cladonia phyllophora	
	Cladonia gracilis	
	Cladonia mitis	
	Cetraria islandica	
Cw	Vaccinium scoparium	4
	Cassiope tetragona	10
	Phyllodoce glandulifera	5
Db	Hylocomium splendens	6
	Dicranium scoparium	4
	Peltigera aphthosa	3
	Peltigera canina	2
D1	Cladonia cenotea	3
	Cladonia alpestris	3
	Crustosa sp.	+

PEDON NO. B3

Date described: August 31, 1977.

Location:	Site located north of youth hostel along old road which runs parallel to present highway. About 0.5 kms from junction of the two roads, the site lies about 30 m southwest into forest stand.
Military Grid Co-ordinates:	11 U MH 906 828.
Landform Classification:	Eolian veneer/inclined moraine.
Parent Material:	Coarse silty, mixed volcanic ash and local detritus/coarse loamy, extremely calcareous mixed, sedimentary.
Site form:	Regular to slightly concave.
Seepage:	Absent.
Drainage:	Well drained.
Solum thickness:	14 cms.
Elevation:	2,060 m. asl.
Slope:	18%, complex.
Sample site position:	Lower - middle slope.
Aspect:	Northeast.
Classification:	Orthic Humo-Ferric Podzol.
Remarks:	Solum developed solely within the surficial parent material and no evidence of till weathering present.

Sample No.	Horizon	Depth (cms)	
42	L-F-H	4-0	Brownish black (10YR 3/2 d) and (7.5YR 3/2 m); undecomposed and well decomposed organic matter, fiberous; abundant roots of all sizes; abrupt smooth boundary; 3-5 cms thick; pH 4.1.
43	Ae	0-4	Light brownish gray (7.5YR 7/1 d), grayish brown (7.5YR 4/2 m); silt loam; weak, fine subangular blocky to weak, fine platy;,soft, friable, non sticky; abundant fine and medium roots; common, very fine pores; abrupt smooth boundary; 3-6 cms thick; pH 3.9.
44	Bf	4-14	Yellowish brown (10YR 5/6 d), brown (7.5 YR 4/4 m); silt loam; weak, medium subangular blocky to weak, fine subangular blocky; soft, very friable, non sticky; plentiful fine roots, few medium roots; common, very fine pores; clear smooth boundary; 8-12 cms thick; pH 5.3.
45	IICk1	14-40	Dull yellow orange (10YR 7/4 d), brown (10YR 4/4 m); loam; moderate, medium and fine subangular blocky; slightly hard, friable, slightly sticky; few, medium roots; common, very fine pores; gradual smooth boundary; 30-40 cms thick; slightly effervescent; pH 7.1.
46	IICk2	40-80+	Yellow orange (10YR 4/4 d) and (10YR 6/4 m); clay loam to loam, amorphous; slightly hard, friable, slightly sticky; few to common very fine pores; strongly effervescent, pH 7.2.

Pedon B3 Results of routine analysis

Sample No.	Depth (cms)	Horizon		Particle Size Distribution (<2mm) (% finer than)										
				Sand						Silt			Clay	
				2.0 mm	1.0 mm	0.50 mm	0.25 mm	0.105 mm	0.053 mm	0.047 mm	0.020 mm	0.005 mm	0.002 mm	0.0002 mm
42	4-0	L-F-H		-	-	-	-	-	-	-	-	-	-	-
43	0-4	Ae		100.0	99.9	97.8	95.3	86.3	73.4	65.3	52.5	16.3	8.2	1.7
44	4-14	Bf		100.0	96.4	91.4	85.8	79.1	72.2	69.5	57.5	32.4	18.6	1.0
45	14-40	IICk1	a)	100.0	90.7	84.8	78.6	69.5	59.6	54.8	41.1	38.2	13.3	1.3
			b)*	100.0	97.3	94.9	91.4	85.8	79.5	78.3	68.0	47.7	34.5	5.8
46	40-80+	IICk2	a)	100.0	89.1	81.8	73.8	63.7	55.7	53.2	42.8	24.7	14.6	2.6
			b)*	100.0	95.2	91.4	89.3	85.5	78.8	76.5	63.0	45.4	30.8	8.4

* particle size distribution after removal of carbonates.

Pedon B3

Sample No.	% sand 2.0-0.05 mm	% silt 0.05-0.002 mm	% Clay < 0.002 mm	% f.Clay < 0.0002 mm	Textural Class	Field Textural Est.	est. % coarse frag. > 2 mm	Db g/cc < 2 mm	$CaCO_3$ equiv. %	pH 0.01M $CaCl_2$
42	-	-	-	-	-	-	-	-	-	4.1
43	31	61	8	2	SiL	SiL	0	0.69	-	3.9
44	29	52	19	1	SiL	SiL	10	1.08	-	5.3
45	43	44	13	1	L	L	55	1.16	51.8	7.1
46	46	49	15	3	L	L-CL	50	1.86	76.6	7.2

Sample No.	Horizon	Total C%	Total N %	C/N Ratio	Exchangeable cations me/100 gms Na	K	Ca	Mg	T.E.C.	Pyro Fe	Pyro Al	Total pyro Extract	$\frac{Fe_p + Al_p}{tot.\ clay}$
42	L-F-H	43.47	-	-	-	-	-	-	-	-	-	-	-
43	Ae	6.11	0.27	22.6	0.10	0.18	2.50	1.64	20.3	0.14	0.12	0.26	0.033
44	Bf	2.88	0.21	13.7	0.17	0.14	11.81	4.00	27.6	0.50	0.41	0.91	0.048
45	IICk1	-	0.12	-	-	-	-	-	-	0.20	0.05	0.25	0.019
46	IICk2	-	-	-	-	-	-	-	-	0.02	0.00	0.02	0.001

Vegetation Description

Vegetation Structure

Stratum	Cover %		Height	Total %
Tree	A1	15	15-20 m	40
	A2	25	5-15 m	
Shrub	B1	2	2- 5 m	24
	B2	22	$<$ 2 m	
Herb	Ch	5	herbaceous	45
	Cw	40	dwarf shrub	
Moss	Db	55	mosses	60
	D1	5	lichens	

Epiphytes: Abundant.

Forest Stand: DBH range: 5-52 cms, mean (est): 25 cms average height of forest canopy: 12 m; largest tree in the plot: height 20 m, DBH 52 cms; regeneration: strong, species *Abies lasiocarpa*; successional stage: mature. Remarks: This site represents a closed forest and is more representative of conditions at somewhat lower elevations.

Species List

Site No. B3

LAYER	SPECIES	% COVER
A1	Picea engelmanni	12
	Abies lasiocarpa	3
A2	Picea engelmanni	8
	Abies lasiocarpa	17
B1	Abies lasiocarpa	2
B2	Abies lasiocarpa	18
	Salix vestita	4
	Potentilla fruticosa	+
C1	Fragaris virginiana	+
	Arnica cordifolia	3
	Erigeron perigrinus	2
	Pedicularis bracteosa	+
	Epilobium angustifolium	+
	Antennaria racemosa	+
	Dryas octopetala	+
Cw	Vaccinium scoparium	25
	Empetrium nigrum	+
	Phyllodoce glandulifera	10
	Cassiope mertensiana	5
Db	Drepanocladus sp.	45
	Barbilophozia hatcheri	5
	Pleurozium schreberi	+
	Dicanum scoparium	5
Dl	Cladonia sp.	4
	Peltigera sp.	1
	Letharia vulpina	+
	Alectoria fremonti	+
	Hypagymnia austerodis	+
	Parmeliopsis ambigua	+
	Parmeliopsis hyperopta	+

Appendix 2. Micromorphological descriptions of selected profiles.

PEDON L1

Horizon and Thickness	Compositional components and remarks*
F-H 4-5 cms	Granic: Phyto-humigranic units are loosely packed and dominated by large (2-5 mm) semi-decomposed root and plant fragments; minor component of mull-like granic units (0.05 - 10 mm) also present.
Upper Ae 4-6 cms	Weakly banded granoidic/granoidic: Isobanded matrigranoidic and fused, elongated granoidic units dominate the fabric; generally these units display weak superimposed banding; units are separated by narrow (0.05 mm), dicontinuous, horizontal craze planes; some areas lack discrete structural units and take on a massive or porphyric appearance; limited matrigranic component present in aggrotubule in the upper 2 cms; the plasmic fabric silasepic, locally approaching isotic, glass shards abundant.
Lower Ae 1-2 cms	Granoidic/granic: Mixed fabric composed of predominantly matrigranoidic (0.2 - 0.5 mm) units along with numerous, randomly distributed, matrigranic and humigranic (0.1 - 0.2 mm) units; the zone is characterized by the incorporation of organic matter and the f-matrix takes on a slightly reddish colour; plasmic fabric is silasepic; this zone represents an area in soil fauna activity and is distinctly different from material above and below it.
Lower Ae Upper Bf 4-6 cms	Banded//banded fragmoidic/granic: Units are horizontally elongated with thickness of 0.2 - 0.4 mm and showing thin (0.05 mm) plasma concentrations on top of the main units; discontinuous ortho joint planar voids separate the banded fabric units; minor component of banded metamatrifragmoidic and matrigranoidic units also present; degree of banding dimishes with depth; incorporation of organic fragments (phytogranic units) occurs occasionally throughout; plasmic fabric is silasepic.
Middle Bf 5-7 cms	Granoidic//granic: This fabric is composed of matrigranoidic and to a lesser extent phyto-humimatrigranic units; f-matrix and the exterior of rare f-clasts display reddish staining; most of the fabric consists of small (0.05 - 0.2 mm) humi and matrigranic units (probably faunal origin) distributed amongst larger (0.3 - 0.8 mm) matrigranoidic units; plant fragments, mainly root sloughings of variable size are found throughout; plasmic fabric is variable, some areas are distinctly isotic while others, especially lower in the zone, display silasepic fabric.

*format according to Pawluk and Dudas, 1978. Can. J. Soil Sci. 58:209-220. Terminology see Methods and Materials, Chapter 3.

PEDON L1 (cont'd.)

Horizon and Thickness	Compositional components and remarks
Upper IIBm 3-4 cms	Porphyric//granoidic porphyric: The fabric is dominated by a vughy porphyroskelic fabric which may become exceedingly vughy and is described as being matri-granoidic porphyroskelic, f-clasts are common and appear to be undergoing considerable weathering; ferrigenous zones and diffuse nodules are also common; occasional, weakly expressed neocutans associated with voids are present and become more common with depth; much less phyto material than in zones above; plasmic fabric is weakly vo-mosepic. (Figure 39).
Lower IIBm 6-9 cms	Porphyric//granoidic-fragmoidic: The fabric shows a matrigranoidic-matrifragmoidic component composed of large (1 - 2 mm) units displaying variable degrees of accommodation; narrow craze planes and meta vughs are both found within the fabric; in-filled voids and clay plugs as well as embedded papules composed of bright yellow material showing unistrial plasmic fabric are found within the matrix of major structural units and increase in number with depth; much of the f-matrix exhibits a dark gray, dense staining; diffuse and discontinuous void argillans are present; plasmic fabric is generally vo-masepic. (Figure 17 and 18).
Upper IICkl 7-9 cms	Porphyric//Plectic porphyric/Chitonic: A complex fabric resulting from depositional stratification; sorted lenses of sands produce a chitonic fabric which is intermixed within components of less sorting and increased f-matrix material about the ortho f-members producing a plectic-porphyroskelic fabric; papules are common and decrease with depth; local vughy areas exhibit distinct, sharply defined yellowish red argillans, but these are discontinuous and limited in their distribution; plasmic fabric is vo-skel masepic. (Figure 19).
Lower IICkl 3-5 cms	Plectic porphyric//fragmoidic: A complex fabric similar to the upper IICkl however a component of horizontally elongated (2 - 5 mm) matrifragmoidic units composed of relatively finer material is present and is considered a result of depositional processes; isolated papules and discontinuous argillans also present, silty matrans are noticable as cappings on larger f-clasts; plasmic fabric is vo-insepic. (Figure 20).
IICk2 (clod)	Plectic porphric: The zone is dominated by the intergrade plectic porphyric fabric; minor ortho-granic component as well; common f-clasts up to 5 cm are common; minor banding seen within some units; plasmic fabric is insepic.

PEDON L3

Horizon and Thickness	Compositional components and remarks
F-H 2 cms	Granic/granoidic: Numerous humi-mullgranic units (0.1 - 0.2 mm) exist as discrete individuals or are fused together to form larger variably sized (1.5 - 4.0 mm) humi-matrigranoidic units; the overall fabric appears clustered and with large packing voids; faunal activity is highly evident, both in terms of the creation of humi-mullgranic units and in the considerable incorporation of mineral material into the organic horizons.
Upper Ae 4-5 cms	Banded//banded granoidic: The fabric is composed primarily of well banded material with horizontally elongated matrigranoidic units displaying super-imposed banding throughout; structural units are separated by narrow (0.04 - 0.08 mm) discontinuous ortho joint planar voids; units are generally thin (0.1 - 0.2 mm) with bands of concentrated plasma (0.05 - 1.0 mm) evident; in some areas the individual units, along with the banding, become rather diffuse leading to the formation of porphyric-like fabric; plasmic fabric is silasepic to isotic. (Figure 9).
Lower Ae 3-4 cms	Granoidic//isobanded granoidic: The fabric is dominated by loosely packed, rounded, matrigranoidic units (0.2 - 0.5 mm); lower portion of this zone shows elongated isobanded granoidic units and the fabric becomes similar to that in the upper Ae; a silasepic plasmic fabric is characteristic of this zone. (Figure 11).
Upper Bf 4-5 cms	Granoidic/granic: The zone is composed of a complex of humi-phyto-matrigranic and matrigranoidic units; the granic units are of the size mode 0.1 - 0.3 mm with larger organic fragments incorporated through; a dominantly humigranic fabric is found within the numerous aggrotubules present, as well as larger matrigranoidic (1.0 - 1.5 mm) units; large (up to 5 mm) f-clasts and a distinct reddish matrix are characteristic of this zone; plasmic fabric is silasepic to weakly insepic. (Figure 14).
Middle and Lower Bf	Weakly banded granoidic: Generally similar to fabric of the upper Bf except that matrigranoidic units predominate and tend to be horizontally oriented and separated by irregular interconnected metavughs; occasional diffuse nodules present as well as fine

PEDON L3 (cont'd.)

Horizon and Thickness	Compositional components and remarks
	(0.5 mm) nodules dispersed through the f-matrix; f-clasts often display considerable weathering and dark coatings of red plasma of iron oxides and/or organic material; plasmic fabric is silasepic to weakly insepic.
Upper IIBml	Isobanded fragmoidic//granoidic: The fabric is dominated by partially accommodating, somewhat elongated and angular matrifragmoidic units of the size mode (1.5 - 3.0 mm), where accommodation is absent, matrigranoidic units of similar size but a more rounded shape occur; metavughs and horizontal planar voids in areas of isobanded fabric are common, occasional, diffuse iron oxide nodules become more distinct with depth and range from very small (0.1 mm) up to quite large (1.0 mm); rare weakly oriented void argillans and diffuse neocutans occur; plasmic fabric is vo-insepic. (Figures 23 and 40).
Lower IIBml 6-8 cms	Granoidic/granoidic porphyric: The fabric is a vughy granoidic porphyroskelic intergrade; some areas show a "spongy" structure and are considered as granoidic; much of the plasmic birefringence is masked by dark oxides or isotropic weathering products; the fabric is often permeated with small (0.2 - 0.5 mm) interconnected, mamillated metavughs and vesicular vughs; silty matrans are often associated with f-clasts as cappings; common, strongly oriented yellow to reddish ferriargillans occur intermittently throughout, most are of variable thickness and associated with void walls although embedded grain cutans are present; occasional papules are present within lower portion of this zone; plasmic fabric vo-skelmasepic. (Figures 21 and 22).
Middle IIBm2 7-9 cms	Granic//granoidic porphyric: A sequence of fabrics from small (0.05 - 0.1 mm) matrigranic units to larger (0.5 - 0.8 mm) units often containing f-clasts to a coalesced vughy matrigranoidic porphyraskelic fabric; as in lower IIBml a "spongy" fabric is evident and the f-matrix displays an overall reddish colour; weathering f-clasts display neoferrans and common ferrigeneous matrans coating their exterior; papules and clay lamellae are rare; plasmic fabric weakly vo-mosepic.
Upper IICkl (clod)	Granoidic porphyric//porphyric: Loosely packed, vughy matrigranoidic porphyroskelic fabric tending towards a more dense porphyroskelic fabric in some

PEDON L3 (cont'd.)

Horizon and Thickness	Compositional components and remarks
	lower portions; numerous ferriargillians associated with vugh walls, occasional, localized quasicutans and ferrigenous neocutans within the f-matrix also present; some evidence of secondary carbonates along transmitting voids; plasmic fabric vo-mosepic to insepic. (Figures 5 and 6).

PEDON P2

Horizon and Thickness	Compositional components and remarks
Upper Ae 2 cms	Granic//granoidic: A mixed fabric composed of ortho-matri-phytogranic and matrigranoidic units; common phytogranic units incorporated throughout the fabric; plasmic fabric is silasepic.
Middle Ae 6-7 cms	Isobanded granoidic/granoidic: The fabric is dominated by large horizontally elongated (0.5 mm) and narrow (0.1 - 0.2 mm) isobanded granoidic units separated by discontinuous ortho joint planar voids; this "microplaty" structure grades into a typical matrigranoidic fabric where roots and/or soil fauna have disrupted the fabric; plasmic fabric is silasepic to isotic and is composed mainly of volcanic ash. (Figure 10).
Lower Ae 4-5 cms	Banded//porphyric: The zone displays classic, well banded fabric characterized by distinct dark reddish brown bands superimposed on a light coloured porphyric background fabric; the bands vary from 0.05 - 0.1 mm thickness and occur from 0.5 - 1.0 mm apart; where they are lacking an isotic porphyroskelic fabric is evident; glass shards and phenocryst minerals comprise most skeleton grains; while voids tend to run horizontally, they are both irregular in shape and discontinuous; plasmic fabric is silasepic to isotic. (Figure 12).
Upper and Middle Bf 7-9 cms	Granic//isobanded granoidic porphyric: A mixed fabric of relatively small (0.04 - 0.1 mm) ortho and matrigranic units coelessing to form larger matrigranoidic units (0.5 - 0.7 mm) of irregular shape, a second mode of granic units (0.6 mm), well rounded and appear isotropic, numerous small iron oxide nodules, f-matrix has an overall reddish appearance and is largely isotic. (Figure 13).
Lower Bf 1-2 cms	Granic: An aggrotuble containing humi-phyto-matrigranic units and displaying an overall dark colour exists as an inclusion within the zone as described for upper Bf.
Middle BC 5-7 cms	Granic/granoidic: Variably sized ortho-humi-matrigranic (0.1 - 0.25) units intermixed with and coelessing to form a somewhat larger and loosely packed matrigranoidic (0.5 - 1.5 mm) fabric; where orthogranic units are coated a minor chitonic component exists; evidences of faunal activity and physical breakup of large f-clasts.

PEDON B3

Horizon and Thickness	Compositional components and remarks
Ae 5-7 cms	Weakly banded granoidic//granic: The fabric is composed of a gradation of units; numerous small matrigranic and phytogranic (0.1 - 0.2 mm) units are fused into larger, still rounded, matrigranoidic units (0.35 - 0.6 mm); most areas show horizontal elongation, with units separated by narrow, discontinuous ortho joint planar voids; aggrotuble exhibits densely packed phyto-humigranoidic fabric; dominantly silasepic plasmic fabric.
Upper Bf 2-3 cms	Granic//granoidic: The fabric is composed of loosely packed humi-matrigranic units (0.05 - 0.1 mm) intermixed with aggregated metamatrigranoidic units; f-matric exhibits bright red colour, stained with iron oxides and/or organic matter; larger f-clasts show adhered matrans; less phyto material than above, internal fabric of rounded matrigranoidic units appears silasepic porphyroskelic.
Lower Bf 4-5 cms	Granic/granoidic: This zone is characterized by a highly "pellety" structure composed of individual and clustered humi-matrigranic (0.07 - 0.12 mm) units; occasional matrigranoidic and larger orthogranic (1.0 - 2.0 mm) units occur throughout; the fabric displays a highly stained colour as in the upper Bf; although structural units are composed of the same materials as above, the fabric appears to have been affected by intense faunal activity; plasmic fabric is silasepic.
Upper IICkl 5-8 cms	Granoidic/granoidic porphyric: This zone is composed of very loosely packed matigranoidic units tending towards a vughy porphyroskelic fabric; large f-clasts display a typical matran capping; the reddish plasma seen in the Bf horizon is lacking, while reddish nodules are rate; no illuvial clay material evident; f-clasts are common, variable in size (2 - 10 mm) and composed mainly of carbonate minerals, ortho and metavughs both common with the porphyroskelic materials; plasmic fabric is silasepic to weakly insepic.
Lower IICkl 5-7 cms	Granoidic/granoidic porphyric: Similar materials fabric as upper IICkl; somewhat more densely packed and the plasma consists of numerous weathering products, particularly reddish staining (iron

PEDON B3 (cont'd.)

Horizon and Thickness	Compositional components and remarks
	oxides); common, large (1 - 5 mm) carbonate rock nodules exhibiting matran cappings and reddish neoferrans; plasmic fabric is insepic.
IICk2 (clod)	Porphyric: A very densely packed fabric, specifically silasepic porphyroskelic; occasional orthovughs show thin, discontinuous calcitans; some areas exhibit dark neostrians within the generally grayish f-matrix material apparently composed of finely divided carbonates, rare papules and diffuse iron oxide nodules also present.